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CORRECTIONS AND INSERTIONS

All contributors to volume 23 have been invited to send corrections and insertions to be made in their papers, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 13, line 21 from top; after Boston. *omit* lines 21, 22, and 23 and *insert* The firing on the flag at Fort Sumter, April 12, and the subsequent attack of a mob in the streets of Baltimore on the Sixth Massachusetts Regiment on its way to aid in the defense of Washington,
" 14, " 13 from top; *for* "Hours of Exercise in the Alps" *read* Semi-scientific Descriptions of Glaciers and Mountaineering in the Alps.
" 92, " 13 from top; *omit* entire line
" 95, " 2 from top; *for* "shows" *read* show
" 96, " 7 from top; *for* "allowed, mentioned" *read* allow mention
" 98, " 14 from bottom; *for* "below" *read* above
" 103, " 6 from top; *for* "as well" *read* as well as
" 103, " 18 from bottom; *for* "form," *read* form;
" 107, " 7 from top; *for* "combines" *read* employs
" 116, " 3 from top; *after* "border" *omit* comma
" 116, " 16 from bottom; *for* "words 'gas' and 'boss'" *read* word "gas"
" 117, " 10 from bottom; *for* "morvan" *read* Morvan
" 123, lines 15, 17, 26, and 29 from top; *omit* "so"

Plate 15, title should read "The Ordovician-Silurian Limestone—Dolomite Belt."
Pages 334, 336, 338, 340, 342, 344, 346 and 348, *for* "L. D." in head-line *read* D.
Page 345, line 14 from bottom, *for* "expected" *read* exported
" 352, " 5 from top, *for* "south corner" *read* southeast corner
" 374, " 18 from top, *for Favosites turbinata read Favosites turbinatus*
" 375, " 18 from top, *beginning with* "although" *should read* although such beds outcrop at the Silurian-Devonian contact at the northern edge of town and some of the wells, etcetera.
" 461, " 17 from top, *for* "slickensides" *read* slickensided
" 462, " 4 from top, *for* "make" *read* makes

BULLETIN

OF THE

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VOLUME 23 NUMBER 1
MARCH, 1912

JOSEPH STANLEY-BROWN, EDITOR

PUBLISHED BY THE SOCIETY
MARCH, JUNE, SEPTEMBER, AND DECEMBER

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

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PROCEEDINGS OF THE TWENTY-FOURTH ANNUAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT WASHINGTON, D. C., DECEMBER 27, 28, 29, AND 30, 1911

EDMUND OTIS HOVEY, *Secretary*

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Session of Wednesday, December 27

The first session of the Society was called to order at 10 o'clock a. m., Wednesday, December 27, at the new National Museum, Washington, D. C., by President Davis, who referred to the pleasure and interest with which the Society met from time to time at the capital, previous meetings having been held there in 1890, 1899, and 1902.

The Secretary then presented the printed report of the Council, which, by vote of Council, was laid on the table till Thursday morning.

ELECTION OF AUDITING COMMITTEE

The Auditing Committee was then elected, consisting of George P. Merrill and E. H. Kraus, and the Treasurer's report was referred to it. At the afternoon session E. B. Mathews was added to this committee.

ELECTION OF OFFICERS

The Secretary declared the vote for officers for 1912, the regular ticket as prepared by the Council being elected, as follows:

President:

Herman L. Fairchild, Rochester, N. Y.

First Vice-President:

Israel C. White, Morgantown, W. Va.

Second Vice-President:

David White, Washington, D. C.

Secretary:

Edmund Otis Hovey, New York City.

Treasurer:

William Bullock Clark, Baltimore, Md.

Editor:

Joseph Stanley-Brown, Coldspring Harbor, N. Y.

Librarian:

H. P. Cushing, Cleveland, Ohio.

Councillors:

Samuel W. Beyer, Ames, Iowa.
Arthur Keith, Washington, D. C.

ELECTION OF FELLOWS

The Secretary then announced the election in due form of the following Fellows:

R. C. Allen, A. B., A. M., Lansing, Michigan.

Robert Van Vleck Anderson, A. B., U. S. Geological Survey, Washington, D. C.

Manley Benson Baker, B. A., School of Mining, Kingston, Ontario, Canada.

Edwin Bayer Branson, A. B., A. M., University of Missouri, Columbia, Missouri.

G. Montague Butler, E. M., School of Mines, Golden, Colorado.

Stephen Reid Capps, Jr., A. B., Ph. D., U. S. Geological Survey, Washington, D. C.

George Halcott Chadwick, Ph. B., M. S., St. Lawrence University, Canton, New York.

Clarence Norman Fenner, E. M., A. M., Ph. D., Geophysical Laboratory, Washington, D. C.

James H. Gardner, M. S., Ph. D., Kentucky Geological Survey, Lexington, Kentucky.

Walter Granger, American Museum of Natural History, New York, New York.

John Sharshall Grasty, A. B., Ph. D., University of Virginia, University, Virginia.

William Otis Hotchkiss, B. S., C. E., State Geologist, Madison, Wisconsin.

Cyril Workman Knight, B. S., Toronto, Ontario, Canada.

Adolph Knopf, B. S., M. S., Ph. D., U. S. Geological Survey, Washington, D. C.

Lawrence Morris Lambe, Department of Mines, Ottawa, Canada.

Elwood S. Moore, B. A., M. A., Pennsylvania State College, State College, Pennsylvania.

Daniel Webster Ohern, A. B., A. M., Ph. D., University of Oklahoma, Norman, Oklahoma.

Sidney Paige, U. S. Geological Survey, Washington, D. C.

Joseph Pogue, A. B., M. S., Ph. D., U. S. National Museum, Washington, D. C.

William Frederick Prouty, B. S., M. S., Ph. D., University of Alabama, University, Alabama.

Elmer S. Riggs, A. B., A. M., Field Museum of Natural History, Chicago, Illinois.

Jesse Perry Rowe, B. S., M. A., Ph. D., University of Montana, Missoula, Montana.

John Joseph Rutledge, B. Sc., Ph. D., U. S. Bureau of Mines, Knoxville, Tennessee.

Joseph Theophilus Singewald, Jr., A. B., Ph. D., Johns Hopkins University, Baltimore, Maryland.

Burnett Smith, B. S., Ph. D., Syracuse University, Skaneateles, New York.

Frank Springer, B. Ph., East Las Vegas, New Mexico.

Clinton Raymond Stauffer, B. S., M. S., Ph. D., Western Reserve University, Cleveland, Ohio.

Lloyd William Stephenson, Ph. B., Ph. D., U. S. Geological Survey, Washington, D. C.

Mayville William Twitchell, B. S., M. S., Ph. D., University of South Carolina, Columbia, South Carolina.

Announcement was then made that the Society had lost the following Fellows by death during the year 1911: Samuel Calvin, S. F. Emmons, Christopher W. Hall, Edwin E. Howell, and Amos O. Osborn, and one Correspondent, A. Michel-Lévy. Memorials of deceased Fellows were then presented as follows:

MEMOIR OF SAMUEL CALVIN

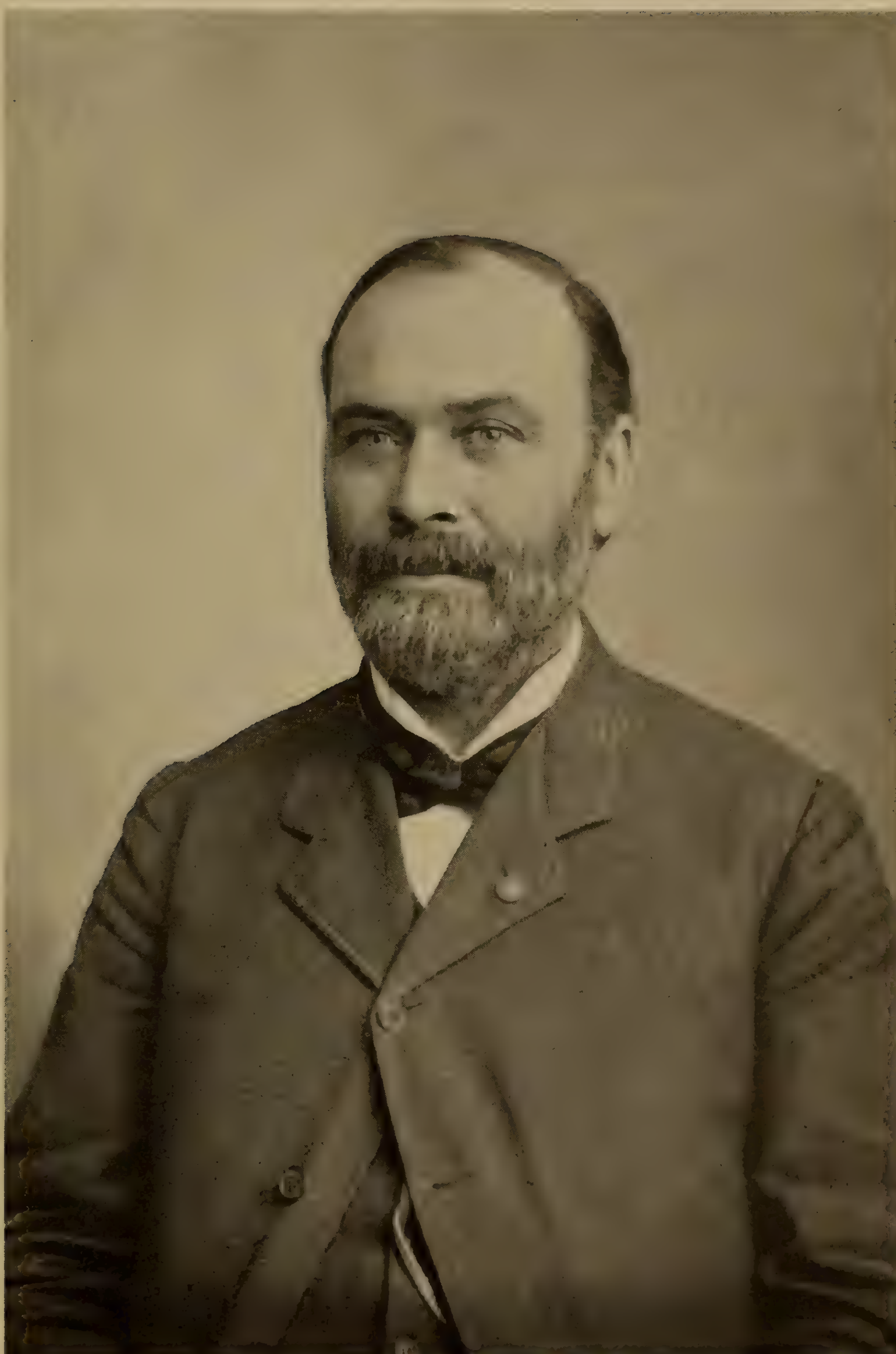
BY B. SHIMEK

The death of Prof. Samuel Calvin at Iowa City, Iowa, April 17, 1911, closed the career of another one of the pioneers in geological work in the Mississippi Valley.

Samuel Calvin was born in Wigtonshire, Scotland, February 2, 1840. At the age of eleven years he was brought to the State of New York by his parents, where three years were spent near Saratoga, and then to Buchanan County, Iowa. Iowa was then largely a wilderness, and his early life, like that of all the sturdy pioneers, was full of hardships and varied experiences. At the age of sixteen he was called to teach in a district school near Quasqueton because of a scarcity of teachers. In these early years he also became an expert cabinet-maker and carpenter. From 1862 to 1864 he was at Lenox College, in Hopkinton, Iowa, first as a student and then as an instructor in mathematics.

In January, 1864, he enlisted in an Iowa regiment as a volunteer, joining the ranks of those who entered the service of their country at a time when men's patriotism was put to the highest test, for the glamor of war had been dulled by nearly four years of a devastating, bloody struggle, and the end was not in sight. On his return from the service he again resumed his work at Lenox. He served as County Superintendent of Delaware County, Iowa, in 1867 and 1868. In 1870 he was married at Hopkinton to Miss Louise Jackson, who, with a son, William, and daughter, Alice (Mrs. Lomas), survives him.

From 1869 to 1873 he served as principal of one of the Dubuque schools, and in January, 1874, he was called to the chair of Natural History in the State University of Iowa, succeeding the late Dr. Charles A. White, whose death preceded his own by only a few months. In conformity with the custom of the day, his chair included geology, botany, and zoology, and it is a striking testimonial to his power as an organizer that out of that work under his guidance have been developed three



Samuel Calvin.

strong departments of the university, requiring the services of eight full professors and a score of assistants.

Cornell College conferred on him the degree of M. A. in 1874 and LL. D. in 1904, and from Lenox College he received the degree of Ph. D. in 1888.

Professor Calvin's scientific training, like that of some of his most noted contemporaries, was obtained largely in contact with the natural world, and he was thus untrammeled by preconceived conceptions or too great dependence upon working hypotheses, which so often hamper independent effort in scientific research. He found his inspiration in a deep love and enthusiastic appreciation of nature, and he brought to his work a critically keen judgment and an uncompromising allegiance to simple truth which made for thoroughness and accuracy.

When he entered upon his scientific work in the later sixties the geological field of the upper Mississippi Valley was but imperfectly developed. In his earlier years he found himself hampered by lack of support, and year after year he carried on his paleontological field work at his own expense, and thus accumulated a notable collection of fossils which is now in the State University of Iowa, and forms a fitting monument to his perseverance. His early studies and teaching experience in various fields gave to his judgment an unusual breadth and balance, and his earlier work in comparative zoology and osteology enabled him to carry out some of his most notable work in later years.

The Iowa Geological Survey was organized largely through his efforts in 1892, and his appointment as State Geologist presented an opportunity for the broadening of his sphere of activity, and he pursued not only the paleontological and stratigraphic studies of the older formations, but entered upon the investigation of the then little understood Pleistocene, and with his associates, who worked under his direction, he made of Iowa classic ground in this field.

He resigned as State Geologist in 1904, but was again appointed in 1906, and served to the time of his death. The twenty volumes of the Reports of the Iowa Geological Survey, published almost wholly under his direction and containing many of his personal contributions, are a splendid testimonial to his zeal, his industry, and his scientific acumen.

Professor Calvin was one of the founders of the American Geologist in 1888, and its editor-in-chief from 1888 to 1894, and associate editor from 1894 to 1905. Of the men who were associated with him in this undertaking only Dr. E. O. Ulrich and Dr. N. H. Winchell remain.

He was active in various scientific societies, holding membership in the American Association for the Advancement of Science (secretary of Sec-

tion E in 1890 and vice-president in 1894); the Geological Society of America (councillor, second vice-president, first vice-president, and president in 1908); the Paleontological Society of America; the National Geographic Society; the Iowa Academy of Sciences (president in 1908), and the Davenport Academy of Sciences. He also served as a member of the National Advisory Board on Fuels and Structural Materials, and as a member of the White House Conference on Conservation of Natural Resources in 1908.

Professor Calvin's work, like his experience, was varied. His scientific activity may be judged somewhat by the bibliography which follows. He himself looked on his later studies of the mammalian fossils from the Aftonian as the most important of his life. His work on the glacial sheets in Iowa, particularly the Iowan, was especially valuable, and the results appear throughout his later papers. He had undertaken a more thorough study of the Iowan border, and there is added tragedy in the death which stilled the master mind, so well equipped to cope with this important problem, before this work was completed. His paleontological work extended over many years and was carried on primarily for the benefit of his students. He described and named a number of fossils, but many more were in his possession awaiting attention. The following list includes the species which he described:

LIST OF FOSSILS DESCRIBED BY PROF. SAMUEL CALVIN[1]

COELENTERA:

Phillipsastrea billingsi Calvin. American Geologist, vol. xii. 1893, p. 111.

VERMES:

Streptindytes, a new genus. American Geologist, vol. i, 1888, p. 27.

Streptindytes acervularia Calvin. American Geologist, vol. i, 1888, p. 27.

MOLLUSCOIDEA:

Rhynchanella alta Calvin. (Described in a private paper.) *circa* 1875.

Rhynchonella ambigua Calvin. Bulletin of the U. S. Geological and Geographical Survey of Territories, vol. iv, no. 3, 1878, p. 729.

Spirifer macbridei Calvin. American Journal of Science, vol. xxv, 1883, p. 433, footnote.

Spirifer urbanus Calvin. Bulletin from the Laboratories of Natural History of the State University of Iowa, vol. i, no. 1, 1889, p. 28.

Orthis infera Calvin. Bulletin of the U. S. Geological and Geographical Survey of Territories, vol. iv, no. 3, 1878, p. 728.

Gypidula munda Calvin. Ibid., p. 730.

Stropheodonta variabilis Calvin. Ibid., p. 727.

Stropheodonta quadrata Calvin. Synonym for *S. calvini* Miller. The original description by Professor Calvin is in Bulletin of the U. S. Geological and Geographical Survey of the Territories, vol. iv, no. 3, 1878, p. 728.

---

[1] The greater part of this and the following list of fossils was prepared by Prof. A. O. Thomas.

Dielasma iowensis Calvin. Bulletin from the Laboratories of Natural History of the State University of Iowa, vol. i, no. 3, 1890, p. 174.

MOLLUSCA:

Schizodus symmetricus Calvin. Bulletin from the Laboratories of Natural History of the State University of Iowa, vol. i, no. 3, 1890, p. 176.

Platystoma niagarense Hall, var. *multilineatum* Calvin. Ibid., p. 177.

Holopen grandis Calvin. Ibid , p. 177.

Euomphalus lativolvis Calvin. Ibid., p. 178.

E. bicarinatus Calvin. Ibid., p. 179.

E. tricarinatus Calvin. Ibid., p. 179.

Bucania perornata Calvin. Ibid., p. 180.

B. cyclostoma Calvin. Ibid., p. 181.

Straparollus claytonensis Calvin. Bulletin from the Laboratories of Natural History of the State University of Iowa, vol. ii, no. 2, 1892, p. 191.

S. pristiniformis Calvin. Ibid., p. 191.

Raphistoma multivolvatum Calvin. Ibid., p. 192.

R. paucivolvatum Calvin. Ibid., p. 192.

Conularia missouriensis Swallow, var. *hersmani* Calvin. American Geology, vol. v, 1890, p. 207.

MOLLUSCA (Con.):

Cyrtoceras luthei Calvin. Bulletin from the Laboratories of Natural History of the State University of Iowa, vol. ii, no. 2, 1892, p. 193.

ARTHROPODA:

Asaphus susæ Calvin. Geology of Wisconsin, vol. iv, 1882, p. 236.

Isotelus florencevillensis Calvin. Iowa Geological Survey, vol. xiii, p. 46, footnote.

MODERN GENUS AND SPECIES NAMED IN HONOR OF PROFESSOR CALVIN

COELENTERATA:

Genus *Calvinia* Nutting. American Hydroids, part I, 1900, p. 77.

MOLLUSCA:

Turbonilla calvini Dall and Bartsch. A monograph of West American Pyramidellid mollusks. Bulletin 68, U. S. National Museum, 1909, p. 48.

ARTHROPODA:

Calosoma calvini Wickham. American Journal of Science, vol. xxviii, 1909, p. 126.

FOSSILS NAMED IN HONOR OF PROF. SAMUEL CALVIN

Invertebrates:

ECHINODERMATA:

Batocrinus calvini Rowley. American Geology, vol. v, 1893, p. 146.

Melocrinus calvini Wachsmuth and Springer. Crin. Cam. of N. A., 1897, p. 300.

Strobilocystites calvini White. Proceedings of the Philadelphia Academy of Natural Science, 1876, p. 28.

Hemiaster calvini Clark. Bulletin 97, U. S. Geological Survey, 1892, p. 90.

MOLLUSCOIDEA:

Stropheodonia calvini Miller. American Paleontological Fossils, 2d ed., 1883, p. 298.

Dielasma calvini H. and W. Twenty-third Annual Report St. Cab., N. Y., 1873, p. 237.

Atrypa calvini Nettleroth. Kentucky Fossil Shells, 1889, p. 89.

MOLLUSCA:

Otenodonta calvini Ulrich. Minn., vol. iii, part II, 1897, p. 596.

Gomphoceras calvini Cleland. Journal of Geology, vol. xv, 1907, p. 465.

Vertebrates:

PISCES:

Dipterus calvini Eastm. Journal of Geology, vol. viii, 1900, p. 38.

Synthetodus calvini Eastm. Iowa Geological Survey, vol. xviii, 1908, p. 233.

He has also left a permanent impress on geological nomenclature by naming the Buchanan gravels, Independence shale, the Platteville, the Delaware, and Hopkinton stages, the Decorah, Brainerd, and Clermont shales, and the Elgin Shaly and Fort Atkinson limestones.

Professor Calvin was especially strong in field work, and in this he impressed every one who had the privilege of working with him by his keenness of observation, his accuracy of correlation, and that unbounded enthusiasm which remained unchecked to the very end of his life.

As a teacher and a man he had few equals. Thirty-seven years of his life were devoted to the students of the University, and no one left his class-room or laboratory without carrying away something more than a mere knowledge of the professor's pet subject, for Professor Calvin was a character builder. Though he could be a stern master he was kindly and sympathetic in his attitude toward those who were associated with him in any capacity, and his kindly helpfulness will long be remembered by those who knew him best. He was impatient only at deception and superficial assumption, and his love of truth and genuineness was equalled only by that modest manhood which was at once the marvel and the model of his students and associates.

The influence of Professor Calvin's life may well be summarized in the words of his old-time friend and associate, Prof. Thomas H. Macbride, who, on the occasion of the thirtieth anniversary of Professor Calvin's service in the University, wrote: "He was a teacher, and thousands of pupils in all parts of the country owe to him the impulse of their intellectual life; he has been an organizer, and the work of natural science in the University today is his; he has been a man of science and the learning of his time acknowledges on every hand its measure of obligation."

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A piece of coal. Popular Science Monthly, vol. xviii, 1881, pp. 610-624, 14 figures.

On the fauna found at Lime Creek, Iowa, and its relation to other geological faunas. American Journal of Science, vol. xxv, 1883, pp. 432-436.

The geological formations of Iowa. World's Exposition at New Orleans, 1884, pp. 1-4.

New species and new genus of Tubicolar Annelida. American Geologist, vol. i, 1888, pp. 24-28.

Notes on the formations passed through in boring the deep well at Washington, Iowa. American Geologist, vol. i, 1888, pp. 28-31.

Observations on the vertical range of certain species of fossils of the Hamilton period in western Ontario. American Geologist, vol. i, 1888, pp. 81-86.

On the chert of the Upper Coal Measures in Montgomery County, Iowa. American Geologist, vol. i, 1888, pp. 116-117.

Description of a new species of Spirifer from the Hamilton group near Iowa City. Bulletin from the Laboratories of Natural History of the State University of Iowa, vol. i, 1888, pp. 28-29.

Notes on the synonymy, characters, and distribution of *Spirifera parryana* Hall. Bulletin from the Laboratories of Natural History of the State University of Iowa, vol. i, 1888, pp. 19-28.

Some geological problems in Muscatine County, Iowa. Bulletin from the Laboratories of Natural History of the State University of Iowa, vol. i, 1888, pp. 7-18.

Iron Butte, Montana. American Geologist, vol. iv, 1889, pp. 95-97.

Note on a specimen of *Conularia missouriensis* Swallow, with Crenulate Cortæ. American Geologist, vol. v, 1890, pp. 207-208.

Some new species of Paleozoic fossils. Bulletin from the Laboratories of Natural History of the State University of Iowa, vol. i, 1890, pp. 173-181.

Additional notes on the Devonian rocks of Buchanan County. American Geologist, vol. viii, 1891, pp. 142-145.

Note on the difference between *Acervularia profunda* Hall and *Acervularia davidsoni* Edwards and Haime. Proceedings of the Iowa Academy of Sciences, vol. i, part II, 1892, pp. 30-32. American Geologist, vol. ix, 1892, pp. 355-358.

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Two unique Spirifers from the Devonian strata of Iowa. Bulletin from the Laboratories of Natural History of the State University of Iowa, vol. ii, 1892, pp. 165-167.

Report on some fossils collected in the Northwest Territory, Canada, by naturalists from the University of Iowa. Bulletin from the Laboratories of Natural History of the State University of Iowa, vol. ii, 1892, pp. 163-165.

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MEMOIR OF SAMUEL FRANKLIN EMMONS

BY ARNOLD HAGUE

Samuel Franklin Emmons was born in Boston, March 29, 1841, and died at his home in Washington, March 28, 1911, lacking only one day to complete his seventieth year. He was the fifth child and third son of Nathaniel H. Emmons, for many years a prominent and highly respected merchant of Boston, engaged in the East India and China trade. His great-grandfather, Samuel Franklin, a resident of Boston, for whom he was named, was a cousin of Benjamin Franklin.

In his boyhood days Emmons attended the best private schools in Boston, and for five years was a pupil in the celebrated Dixwell Latin School. Mr. Dixwell had the well deserved reputation of being a gentleman of broad culture and refined manners and admirably qualified to prepare boys for college. Before establishing his private school he had filled the position of principal of the well known Public Latin School of Boston. In addition to the prescribed courses to meet the requirements of college examinations, special attention was given to English composition, for which Mr. Emmons was always grateful. As he was well advanced in all preparatory studies, he was given permission in his last school year to take a special course in physical geography, a study that appealed to him, but what caused particular pleasure was the construction of maps from memory, without aid of instrumental field notes. In later years, while engaged in exploration work in the far West with-

S. F. Emmons.

out maps, he realized that these boyhood studies stood him in good service.

He entered Harvard College in his seventeenth year, and was graduated in the class of 1861 with the degree of A. B. His class, upon graduation, numbered 82, and, though small even for that time, furnished its full quota of men who later occupied influential positions in the world and did their life work well, who were an honor to their university and to their classmates. Among them stood Samuel Franklin Emmons.

A fellow-student writes of him: "Emmons deserved praise for the fidelity with which he applied himself to his studies. He could always be depended upon as a man who was thoroughly prepared. His constancy in this respect won our admiration and esteem. I think he may be set down as one of the most diligent students of the class."

The seniors of 1861 had an experience which has fallen to the lot of no other class. The stirring events preceding the breaking out of the Civil War, followed by the election of Abraham Lincoln, created a profound interest in political and national affairs in the debating clubs and daily life of the students. Several of the class, including Emmons, organized a drilling club for military purposes, receiving instruction in Boston. The attack in the streets of Baltimore on a Massachusetts regiment while on its way to Washington to attend the inauguration, and the subsequent firing on the flag at Fort Sumter, April 19, naturally aroused intense patriotic feeling. Intercollegiate sports, including the Yale-Harvard boat race, were abandoned, much to Emmons' disappointment, as he had given much time to his favorite exercise, rowing, and he had every expectation of handling an oar in the coming university race.

Events changed many matured plans. Several of the class, under special authorization of the faculty, were allowed to enter the army before graduation. Later many others volunteered their services to the Government. Emmons desired to go to the war, but reluctantly yielded to the expressed wish of his parents, who were averse to his enlistment. A long cherished ambition of the elder Emmons was that at least one of his sons should pursue a professional career. As Frank from boyhood had always shown the habits of a student, and was then completing a collegiate course, the choice naturally fell upon him, and as his own taste led him to prefer an out-of-door life he began early to look forward to some form of engineering as a profession, although at that time he held no definite plans in mind. He had suggested to his father that upon leaving college he should go to Europe for a three-years' course of study, but the parent at that time could not bring himself to agree to so long an absence.

In the spring of 1861, owing to the ill health of his mother, the family physician recommended for her restoration a summer trip to Europe. Probably because he was at that time the most available person to accompany her, and possibly because it took him out of the country during the early months of a disastrous civil strife, he was selected by the family to take his mother abroad. After passing creditably his final examinations, a few days previous to the closing exercises of the college, he sailed in June, on a Cunard steamer, out of Boston Harbor for England, with his mother and a younger brother who was nine years of age. During the summer they made a somewhat extended journey, traveling as far as Switzerland, which Emmons thoroughly enjoyed among the glaciers and mountains, having read and re-read, while in college, with youthful enthusiasm, Tyndall's "Hours of Exercise in the Alps." November saw them again in England, where he bade good-bye to mother and brother, who sailed for home. Lingering for a while in England, December saw him again in Paris bent upon some line of scientific work, but still undetermined in his own mind just where and what course of study to pursue.

It was his good fortune shortly after reaching Paris to make the acquaintance of the late Eckley B. Coxe, of Philadelphia, who was then a student at the École Impériale des Mines. It was an acquaintance which soon ripened into friendship lasting till the death of Coxe in the early days of a successful professional career. Emmons always regarded this meeting with Coxe as a turning point in his own life, and, acting upon the advice of his friend, he decided to prepare for the École des Mines. He found his college French totally inadequate for his purpose and his equipment for passing the required entrance examinations far from satisfactory. Settling down in the Latin quarter among the students in February of the following year, he worked assiduously for nine months under private tutors, among other things going over the entire field of mathematics from arithmetic to differential calculus, without the use of text books, depending wholly upon verbal demonstration. In after life he alluded to this instruction as a masterly and brilliant course compared to anything in his previous student life. By good luck he was able to enter as a private pupil the chemical laboratory of the celebrated Prof. Adolf Wurtz, where he became sufficiently grounded in both chemistry and physics to enable him later to follow advanced studies in his scientific course.

In the autumn he entered the École des Mines as one of the few students enrolled in the class known as Éleves Externes, a privilege in those days granted only upon application of the foreign representative of

other friendly governments, a privilege Emmons obtained through the courtesy of Hon. Wm. L. Dayton, the American Minister to France. Here Emmons worked industriously for two academic years, from November, 1862, to the summer of 1864. The faculty was regarded in Paris as an exceptionally brilliant one, but the two men who inspired the American student with enthusiasm were Elie de Beaumont and Daubree.

At the close of the school year Emmons concluded that it would be more to his advantage to spend the last year of study in Germany rather than complete the course in Paris. Two considerations influenced him: the one was that the practical side of mining engineering was taught more in detail at Freiberg, and the proximity of the mines to the town rendered access to the works far more convenient. The other was a desire to learn something of the German school of geology. Leaving Paris, he entered the Bergakademie at Freiberg, Saxony, in the early summer of 1864, in time to take the practical course of underground work in the mines, and also to familiarize himself with the language before lectures began in October. He remained in Freiberg till midsummer of 1865.

From Heidelberg, where I had devoted most of my time to chemistry and mineralogy in Bunsen's laboratory, I reached Freiberg in the spring of 1865, meeting Frank Emmons for the first time. His greeting was most cordial, and he gave me much kindly advice based on the longer experience in the Bergakademie, advice which I found most valuable. Although he intended to follow the profession of a mining engineer, he devoted relatively little time to mechanical engineering, while I was always ready to lay aside metallurgical studies for field geology. Together we took all the week-end excursions with dear old Bernhard von Cotta, visiting many parts of Saxony, and studying petrology as laid down in that now antiquated text book, Cotta's "Die Gesteinlehre" (Zweite Auflage, 1862). Many an evening Emmons and I spent together over the map of Saxony, acquiring our initiative experience in geological cartography, which later stood us in good service. Both came to realize the influence of Cotta upon our future careers. In this way an intimate friendship, which lasted through a lifetime, was formed during these few months of Germon student life. Emmons left Freiberg in midsummer and traveled through parts of Europe, visiting many of the important mining centers. He spent the winter in Italy, making Rome his headquarters, and returned to Boston in June, 1866, after an absence of five years.

I returned to my home in Boston in December, 1866. A few weeks later, while in New York, I was offered a position as assistant geologist

on the Geological Exploration of the Fortieth Parallel by my former fellow-student at the Sheffield Scientific School of Yale, Mr. Clarence King. Mr. King was then passing the winter in Washington, endeavoring by his individual efforts, aided by influential members both in the Senate and House of Representatives, to obtain the necessary legislation for carrying out the purposes of the expedition. The authorization was enacted by Congress without the customary delays. At the suggestion of Mr. King the official direction of the expedition was placed under the Chief of Engineers, Gen. A. A. Humphreys, notwithstanding that the work was to be carried on entirely by a civilian service. Mr. King was placed in full charge of the work and authorized to draw up a plan for the organization of the expedition, which he immediately proceeded to do, and which received official sanction. On my return to Boston I sought out my friend Emmons, told him of the offer I had received, and my acceptance of the position. He replied: "That is just the kind of work that would suit me. I heartily congratulate you." Shortly afterward I brought King and Emmons together, with the result that Emmons accepted a position as volunteer assistant, and in the following winter received an official appointment as assistant geologist, much to the gratification of all members of the organization.

On May 1, 1867, several members of the scientific corps, including Emmons, sailed from New York for San Francisco by way of the Isthmus of Panama and the Pacific mail steamer, along the coast of Mexico and California, the trip occupying three weeks. At that time the only other available route was by Wells, Fargo & Company's overland stage, a tedious, not to say dangerous, journey. After a delay of several days in San Francisco, gathering information of various kinds, including geographical data along the proposed line of the Central Pacific Railway across Nevada and Utah, a camp was established at Sacramento for equipment purposes. A ride of a few days across the high Sierras and down the eastern slope brought the party, early in August, to its first working camp on Truckee River, not far from the now flourishing town of Reno. The camp was pitched on what was then the western edge of the great American sage-brush desert, sparsely inhabited by a few frontier settlers, expecting to become rich when the railway came along. There were practically no serviceable maps, and but slight knowledge of the country except along the overland stage road. Some idea of the condition of things may be gained from the fact that the party was sometimes dependent upon friendly Indians for valuable information. Today it may seem difficult to realize that it was deemed essential by the War Department to provide a cavalry escort of twenty-five men to guard

life and property. Not infrequently a mounted soldier accompanied a geologist when it was deemed unwise for any one to be quite alone on the mountains. Under such conditions the work, from necessity, took on more the nature of a reconnaissance than a survey.

The exploration as originally planned by Mr. King, modified later by experience and the needs of the country, required a survey of an area 100 miles in width, stretching from the Great Plains of Wyoming and Colorado westward to the eastern boundary of California, and always including the proposed route of the first Transcontinental Railway. This comprehensive plan called for a topographical map on a scale of four miles to the inch, based upon a system of primary and secondary triangulations, the elevations to be determined by a series of careful and frequent barometric readings, referred to well established main camps. On these topographic maps the geology was to be laid down. It should be borne in mind that such finished maps were seldom in the hands of the geologists till a year after the completion of field work.

In addition to the corps of geologists and topographers, the party included an ornithologist, botanist, and, what was at that time an unheard of innovation, a skilled photographer. Under existing conditions, due in part to the large areas to cover in the limited time at our disposal and the lack of adequate funds to do the work commensurate with the standard of excellence desired, geology and topography were compelled to go hand in hand. Two well equipped organizations were constantly in the field, serving in quite separate areas, one known as the Emmons party, the other as the Hague party. Mr. King had his own camping outfit, dividing his time between one or the other party, or else conducting special investigations, and occasionally visiting areas outside the broad belt of exploration. Not infrequently both parties came together to talk over the complexities of geological problems. For instance, Emmons and I agreed regarding the front face of the Wasatch Mountains; King at first dissented from some of these conclusions, but was finally won over to our point of view. Again, Emmons and I disagreed on some structural problem connected with the Uinta Mountains. After much discussion King sided with Emmons, and the geology was represented on the maps in accordance with this decision. In this instance I declined to agree with them.

The short season of 1867 was devoted exclusively to western Nevada, in what was generally referred to as the Humboldt country, from the river of that name, whose principal tributaries had their sources on the Nevada plateau. The following year carried the survey across the remaining Great Basin ranges as far as the mountains bordering the west-

ern edge of Salt Lake Desert. In 1869 field work was mainly confined to the desert country bordering the lake and the strongly contrasted Wasatch Mountains. The year was signalized by the coming together of the two railway systems, one from the Missouri, the other from the Sacramento, the connecting rail, with its silver spike, being laid just north of Great Salt Lake. In a sense it was an inspiration, as the practical reasons for our work were to make known the resources of a country to be opened by railway communication. At all events, it greatly facilitated the operations of the survey. From the Wasatch eastward the belt of exploration traversed the elevated Mesozoic and Tertiary areas of Utah and Wyoming, crossed the relatively low divide separating the drainage of Green River from that of the North Platte, and, continuing eastward, included the Laramie plains and the northern extension of the Front Range. Mr. Emmons gave his attention mainly to geological problems connected with Green River Basin and to Uinta Range and its dependencies. The field work was finally completed in the autumn of 1872.

The first winter was spent in Virginia City, in a study of the Comstock Lode and the geology of Mount Davidson and the adjacent country, situated just south of the southern line of the area of exploration. In successive years winter quarters were established either in San Francisco, Washington, or New Haven. After the completion of field work the offices for the final preparation of the report, with its accompanying atlas, were located in New York. Here Mr. King and his two colleagues worked together and lived together in ties of closest friendship.

In the first volume of the report issued, but volume III of the published series, will be found a chapter by Mr. Emmons on the "Geology of the Toyabe Range," accompanied by a map of those isolated mountains which extend in a north and south direction for over 60 miles, and at that time already well known for their silver deposits. The same volume contained a shorter paper entitled "Geology of the Egan Canyon District." Both are of interest as being his first scientific publications. In his field work he endeavored to visit every locality where ore was reported, yet it was characteristic of the man that he invariably began his examination of such localities by a study of their geological features before taking up the occurrence of any ore bodies.

Emmons' great work, so far as the exploration of the Fortieth Parallel is concerned, will be found in the report on the Descriptive Geology, volume II of its publications. The entire report is the work of the two assistant geologists. It was presented to Mr. King in January, 1877, and by him transmitted, the same month, to Gen. A. A. Humphreys.

This volume, containing 890 pages, was printed by the close of the year and issued soon after. In it is a continuous description of the country, treated geographically, beginning on the Great Plains and progressing westward across the widest part of the northern Cordillera. An endeavor is made to give the structural details and salient geological features lying between the meridian 104 degrees west and the meridian 120 degrees west, the latter being the eastern boundary of the State of California. The volume of atlas maps upon which the early geology was laid down, including the accompanying geological cross-sections, bears the imprint of 1876. Throughout all these years Emmons worked assiduously and with unfailing enthusiasm. Upon completion of the Descriptive Geology, after ten years of service, Emmons resigned his position to pay attention to personal matters.

The act of Congress creating the Bureau of the Geological Survey and placing it under the Department of the Interior was approved March 3, 1879; three weeks later the President nominated Mr. Clarence King as its first Director; on April 3 the Senate confirmed his nomination, and on May 24 Mr. King took the prescribed oath. By this legislation all existing surveys and exploring parties ceased to have Congressional authorization.

One of Mr. King's first official acts was to secure the experienced services of Mr. Emmons, and on August 4 of that year appointed him Geologist in Charge of the Rocky Mountain Division, with headquarters at Denver. The first two lines of his instructions read as follows: "You will devote the first years of your administration of your division exclusively to a study of the mineral wealth of the Rocky Mountains." In accordance with these instructions he was requested to prepare, without delay, a monograph on the Leadville region. The Geological Survey having undertaken the collection of the statistics of the precious metals in connection with the Tenth Census, the work was placed in charge of Mr. Emmons and Dr. G. F. Becker, who were authorized to prepare the statistical schedules and to employ the necessary staff of assistants. The men whom they selected were for the most part mining engineers. The results of the work were published in volume XIII of the series of Census reports. A feature of the volume is the publication of geological descriptions of the more important mining regions, and Mr. Emmons gives, for that time, an admirable chapter entitled "Geological Sketch of the Rocky Mountain Division."

Notwithstanding the time required for the Census volume, Emmons devoted the greater part of his personal attention and energy to the Leadville monograph. He brought to the task a well trained mind and

the exceptional experience of ten years on the Fortieth Parallel Survey; indeed, the monograph shows the influence of the earlier work and his method of thought. Nowhere is this more clearly shown than in his decision to acquaint himself with the geology of the Mosquito Range before taking up such intricate problems as the ore deposits undoubtedly presented. He felt he might be led into error or fail to grasp essential phenomena of ore deposition unless familiar with the structural features of the adjacent country. This mental attitude of Emmons has been well brought out by Whitman Cross, his field assistant and daily companion at Leadville. Emmons conquered in a masterly way the details of the complex ore bodies, and he undertook to solve no problems until he assured himself that he knew his ground. Even as early as the autumn of 1880, in his report to the Director of the Survey, he presented many essential features of the region. An abstract of the monograph on the geology and mining industry of Leadville, accompanied by an admirable geological map, was published in the Second Annual Report of the Director, and served to meet the needs of the engineers working on the ground. The monograph itself, however, was held back for finishing touches and the results of chemical investigation, although the method of presentation and final conclusions remained essentially the same.

The monograph and atlas, containing 35 sheets of maps and sections, appeared in 1886. It attracted immediate attention not only of geologists and practical mine workers, but of all classes of scientific men. It won for its author an international reputation, being received both in Europe and America as a work of the highest order. Since its organization, practically no single publication of the Geological Survey has exerted a more beneficial influence and stimulated more discussion. It everywhere aroused investigation of the origin of ore deposits, and similar studies were prosecuted elsewhere throughout the northern Cordillera. The volume became a model for younger economic geologists. One thing which greatly aided the success of the monograph was the masterly, orderly way in which the author arrayed his facts, and the clear, concise English in which they were presented. After twenty years of active mining operations at Leadville and the exploitation in many directions of new ore bodies, Mr. Emmons, aided by Mr. John D. Irving, renewed his investigations, with the intention of bringing the earlier work up to date. Under the title of the "Downtown District of Leadville, Colorado," the salient features of this reexamination, with the light thrown by new discoveries, were issued as a bulletin of the Geological Survey, both names appearing as joint authors. Owing in part to the failing health of Mr. Emmons, the completion of this study has been

delayed, and since his sudden death has been still further postponed, but the manuscript was left in such shape that it can be edited by his colleague as a fitting close of an earnest career. It is worthy of note here that, notwithstanding all recent developments, Mr. Emmons' conclusions were not essentially changed, but, on the other hand, additional evidence tended rather to confirm his original views, with some modification and revision.

During the following years of Emmons' active duties most of his important contributions to geological science were issued as official documents of the Geological Survey. As they are accessible to all, and the titles are found in the list of his scientific writings appended to the biographical sketch, it seems unnecessary to mention them all, considering the limited space available. They appear in one or another of the many forms of publications adopted by the Government Bureau. Several of the more important of them were published as descriptive texts accompanying folios of the Geologic Atlas. Many of these writings are of the highest value and bring out his power of presenting geological details in a lucid, simple style. In some of these he was the sole author, while in others he shared with his assistants the preparation of the text. Among these folios may be mentioned the "Geology and Mineral Resources of Elk Mountain," "The Butte Special," "The Tintic Special," representing widely separated mining areas in Colorado, Montana, and Utah. To the annual reports he contributed a number of articles, among them an exhaustive one entitled "Mines of Custer County, Colorado," which appeared in the seventeenth report, issued in 1896. In the same year there was issued from the press the well known and elaborate monograph on the "Geology of the Denver Basin," a volume devoted to structural problems of the broad region of country lying east of the Front Range, a work in striking contrast to Mr. Emmons' more recent contributions in the line of economic geology. In this volume he is aided by his two principal assistants in Colorado, Mr. Whitman Cross and Mr. George H. Eldridge, who furnished a large part of the text. In the series of Professional Papers published by the Survey may be found articles from Mr. Emmons' pen, serving as introductions to the work of younger men, upon mining districts in the far West.

Notwithstanding the fact that administrative duties occupied so large a share of his time, Mr. Emmons was able to contribute to scientific journals and societies on a wide range of geological subjects, including dynamic problems, orographic movements, and the many phases of the genesis of ore bodies. In this connection it is only necessary to mention his paper on Secondary Enrichment of Ore Deposits. Mr. Emmons'

keen interest in the structural features of mining areas outside of his own country is shown in his paper on the "Geological Literature of the South African Republic," printed in the Journal of Geology. Within a few months of his death he published articles on the Cananea Mining District of Sonora, Mexico, and the Cobalt Mining District of Ontario.

In strong contrast to these technical papers is his loyal and sympathetic tribute to his old and dear friend, Clarence King, in the biographical memoir read before the National Academy of Sciences.

As early as 1874 Mr. Emmons was made a Fellow of the Geological Society of London, and at the time of his death was one of the oldest members in this country. Throughout this long period he always kept himself in touch with its publications, especially contributions which treated of the geology of unexplored parts of the world. He joined the American Institute of Mining Engineers in 1877, took an active part in its proceedings and discussions, and was elected three times as one of its vice-presidents. He was one of the founders of the Geological Society of America, and chosen its President in 1903, delivering, on retiring, a notable presidential address on "The Theories of Ore Deposition Historically Considered." At the time of his residence in Denver, while in charge of the geological work in Colorado for the United States Geological Survey, he aided in the organization of the Colorado Scientific Society, and was elected its first president in 1882. The society now ranks among the most active scientific bodies in this country. In 1892 he was elected to membership in the National Academy of Sciences. He was also a member of the American Academy of Arts and Sciences, the American Philosophical Society, the Washington Academy of Sciences, and the Geological Society of Washington, of which he also served one term as president. He was an honorary member of the Société Helvétique des Sciences Naturelles.

The fifth session of the Congrès Géologique Internationale met at Washington in the summer of 1871. Mr. Emmons ably filled the position of General Secretary, which was in no sense a sinecure, requiring months of arduous work, as a large share of the responsibility for the success of the Congress fell upon his shoulders. The conditions for such meetings in this country were essentially different from those in such European capitals as London and Paris. Ever afterward he took an active interest in similar congresses, and, attending several of them as delegate from America, served as vice-president at St. Petersburg in 1897, Vienna in 1903, and Stockholm in 1910, taking part in many of the more important geological discussions specially organized for the different congresses.

During his whole life Mr. Emmons' personal appearance had distinction: tall, erect, and slender, his carriage was graceful and unstudied. In the early days of his out-of-door professional work he was extremely active and alert. While he may have had a certain enjoyment in the pursuit of large game, he always seemed to prefer a long-range shot, perhaps at a rabbit in the sage-brush or a grouse in the pine timber. It was the exactness and finish of the shot, rather than the bagging something, that he cared for. A good mountain climber, he disliked a long walk on level ground. While in Leadville he wrote to a friend: "I fear boyish exuberance has left me, but keen zest for field work is as strong as ever." The probable explanation of this attitude can be traced to the fact that mental effort and physical exercise had to go together, and before long the sense of responsibility, which was always a strong characteristic, got the better of enjoyment of mere bodily exhilaration.

During the thirty years of his active service in the Geological Survey he gave to it a thoroughness and lofty devotion. It he demanded high standards of scientific work from those with whom he was associated, he afforded an example by maintaining them himself. While in charge of the Division of Economic Geology he gave personal supervision to the investigations of others, and never wearied in aiding younger men, training them in methods of work, even advising them as to the form of recording their notes. He always sought to inspire them with love of research for its own sake. He often said, in the kindliest way, of young men fresh from the technical schools: "They have excellent powers of observation, but their English is wretched." They all loved Mr. Emmons and kept for him their appreciation and respect, and he cared very much for their affectionate regard. Under a somewhat indifferent manner he had a warm and tender nature. His closest friends, those of a lifetime, never knew him to be guilty of an unworthy action, and if he ever cherished a resentment it was not without good cause. He was always ready to discuss differences of opinion in a cool, dispassionate way, showing a desire to get at the truth rather than to carry his own point. He was charitable and modest, while preserving with proper dignity the high professional and personal position he had so honestly earned for himself.

His later days were, it is to be feared, full of patient endurance of physical pain—it was patient endurance—but he worked all the time and was kindly and gentle always. The younger men of his profession may not always have realized how helpful he had been to them until he could help them no more. His oldest friends, with whom he had built up his character, as well as his professional standing, grieved for him

most because they knew him best. There were many of these friends all over the world, but none were so close as the few with whom he worked as a young man.

While for a long time Mr. Emmons had been in failing health and the cause of anxiety to all, the final end came as a surprise to family and friends. He passed away in peaceful, restful sleep during the early hours of the morning. He left a noble record of life's work well performed.

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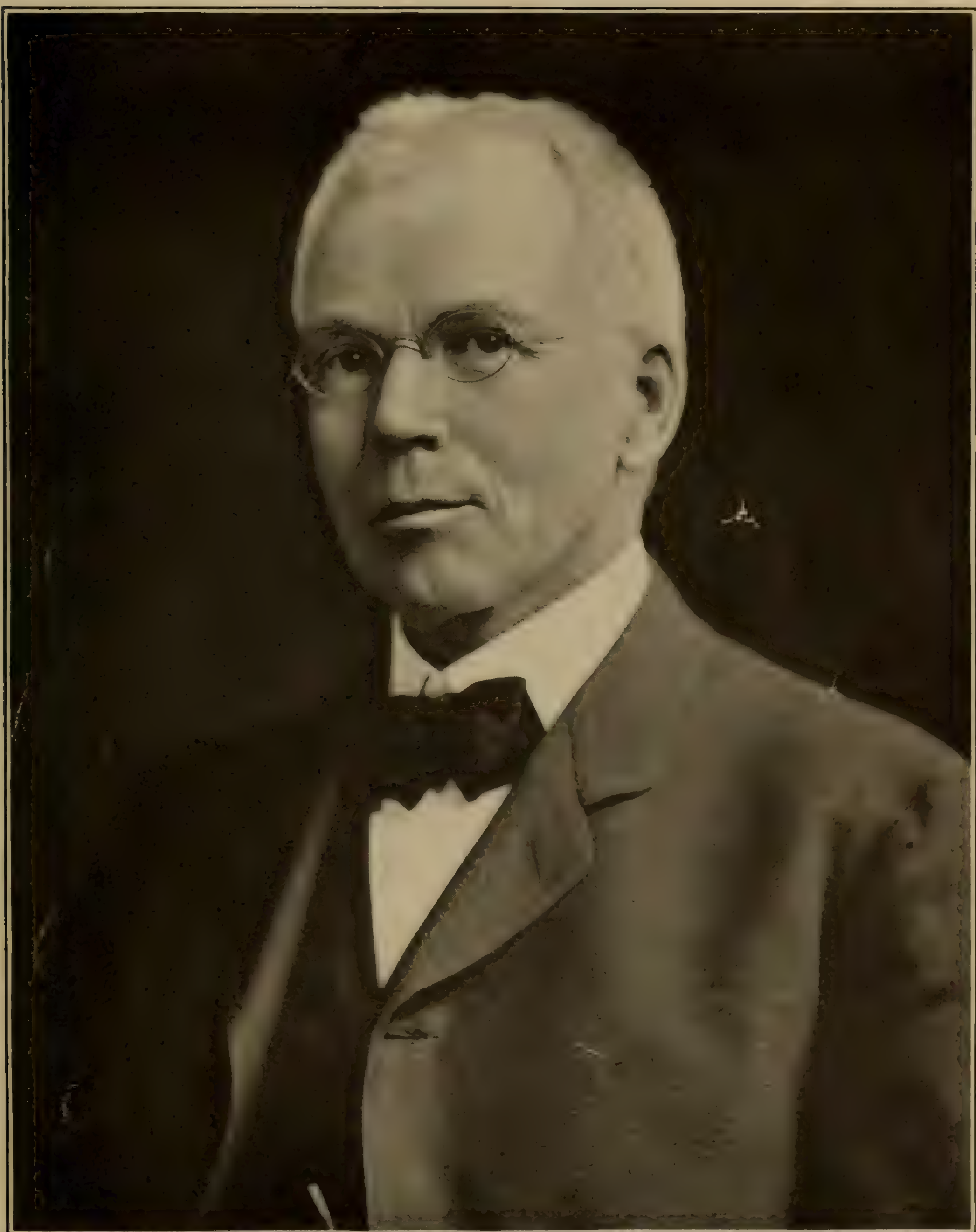
MEMOIR OF CHRISTOPHER WEBBER HALL

BY NEWTON H. WINCHELL

Prof. C. W. Hall, whose death took place May 10, 1911, at his home in Minneapolis, was born at Wardsboro, Windham County, Vermont. He attended the district school and the academies at Townsend and Chester. He was graduated from Middlebury College, Vermont, in 1871, and at once accepted the principalship of the academy at Glens Falls, New York, but the next year removed to Minnesota, where he was elected principal of the High School at Mankato, and in 1874 superintendent of the public schools of Owatonna. He studied geology and allied subjects about two and one-half years at Leipzig, returning to Middlebury College in 1877. In 1878 he was employed as an assistant in the department of geology under Prof. N. H. Winchell, at the University of Minnesota. He also had a quasi-connection with the State geological survey, but his actual field work in geology in Minnesota was either private work or was for the United States Geological Survey. In 1879 he was assigned by the regents to the instructional work in geology and allied branches of science, and he continued in charge of that work until his death, the departments of Animal Biology and of Botany meanwhile developing into coördinate rank.

Professor Hall was largely instrumental in the establishment of the School of Mines of the University of Minnesota, and for a few years he was dean of a school composed of engineering, metallurgy, and mechanic arts, a combination which in the formative stages of the university was found to be incongruous. Each of these departments soon expanded into a separate college, with its own dean and faculty. In 1898 Professor Hall spent the most of a vacation year in Germany.

For many years Professor Hall was active in the Minnesota Academy of Science, especially as secretary, and on him fell many of the executive burdens. He was also president of the Academy in 1901, 1902, 1904, and 1905. He edited the bulletins of the Academy for many years. He



C. W. Hall

was a Fellow of the American Association for the Advancement of Science and vice-president (Section E) in 1910, Fellow of the Geological Society of America, and a member of the National Geographic Society and of the Society for the Promotion of Engineering Education. Professor Hall was a Congregationalist. He married, first, Ellen A., daughter of Hon. Mark H. Dunnell, congressman from Minnesota, in 1876, and, second, in 1883, Sophia Seely Haight. Of his family only a daughter, Sophia, survives him.

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MEMOIR OF EDWIN E. HOWELL

BY GROVE K. GILBERT

On Easter Sunday, Edwin Eugene Howell died at his home in Washington. Geologists, physiographers, and educators of our country thereby lost an efficient and appreciated ally.

In the year 1861 the late Henry A. Ward, then professor of geology in the University of Rochester, erected on the college campus a building which he called Cosmos Hall and which was devoted to the assemblage and preparation of scientific material for museums of natural history. The establishment thus instituted grew and developed, and it still flourishes. Its work was performed largely by young men of congenial tastes, who there acquired the practical experience which commended them later to the trustees of larger responsibilities. It thus served incidentally as a training school in the natural sciences and especially in certain branches connected with museums. Among its graduates are Frederic A. Lucas,

Edwin E. Howell

director of the American Museum of Natural History; William T. Hornaday, director of the New York Zoological Park; Charles H. Townsend, director of the New York Aquarium; F. C. Baker, curator of the Chicago Academy of Sciences; William M. Wheeler, professor of economic entomology at Harvard University, and Henry L. Ward, director of the Milwaukee Public Museum, and in addition to these the writer, who ranks himself somewhat proudly as senior alumnus. This was Howell's school, his real school despite the fact that the biographies mention only the country schools of his native county and the University of Rochester, which recognized certain special studies by making him a master of arts. He entered it in 1865, at the age of 21, and took his diploma—so to speak—in 1872.

For two years he was a geologist of the Wheeler Survey and then for a year held a similar position in the Powell Survey, his work consisting of geologic reconnaissance in Utah, Nevada, Arizona, and New Mexico. Then, having become satisfied that this occupation was not the one for which he was best fitted, he resigned his position and returned to the Rochester Museum, becoming a partner where he had before been an assistant. A few years later he removed to Washington, where he established "The Microcosm," an institution somewhat similar to Ward's Cosmos Hall, but devoted more particularly to geologic material and subjects. The modeling of relief maps, in which work he was a pioneer—if not *the* pioneer—for the United States, soon became a specialty; and his monument for a generation at least will consist in the plastic representations of physiography, topography, and geologic structure which adorn the halls and walls of museums and school-rooms throughout the continent.

He was one of the founders of the Geological Society of America and was connected with a number of other scientific associations, national and local, but he rarely contributed to their discussions. Besides the report on his geologic field work, his contributions to scientific literature included only brief descriptions of meteorites.

Personally Howell was quiet, unassuming, and sincere. His recognized integrity was an important factor in his business success. If he had enemies or detractors, I have not met them. His modeling was not distinguished by its artistic quality, but was realistic whenever the material from which he worked was full. His clients found him ever clamorous for facts and anxious to revise work at any stage if it could thus be made more truthful, and his clients, who were numerous among the investigators and teachers of geology and geography, were also his friends.

He was born March 12, 1845, in Genesee County, New York, and

passed his boyhood on a farm. In 1880 he married Annie H. Williams, an artist. His wife died in 1893, but a son and daughter survive him.

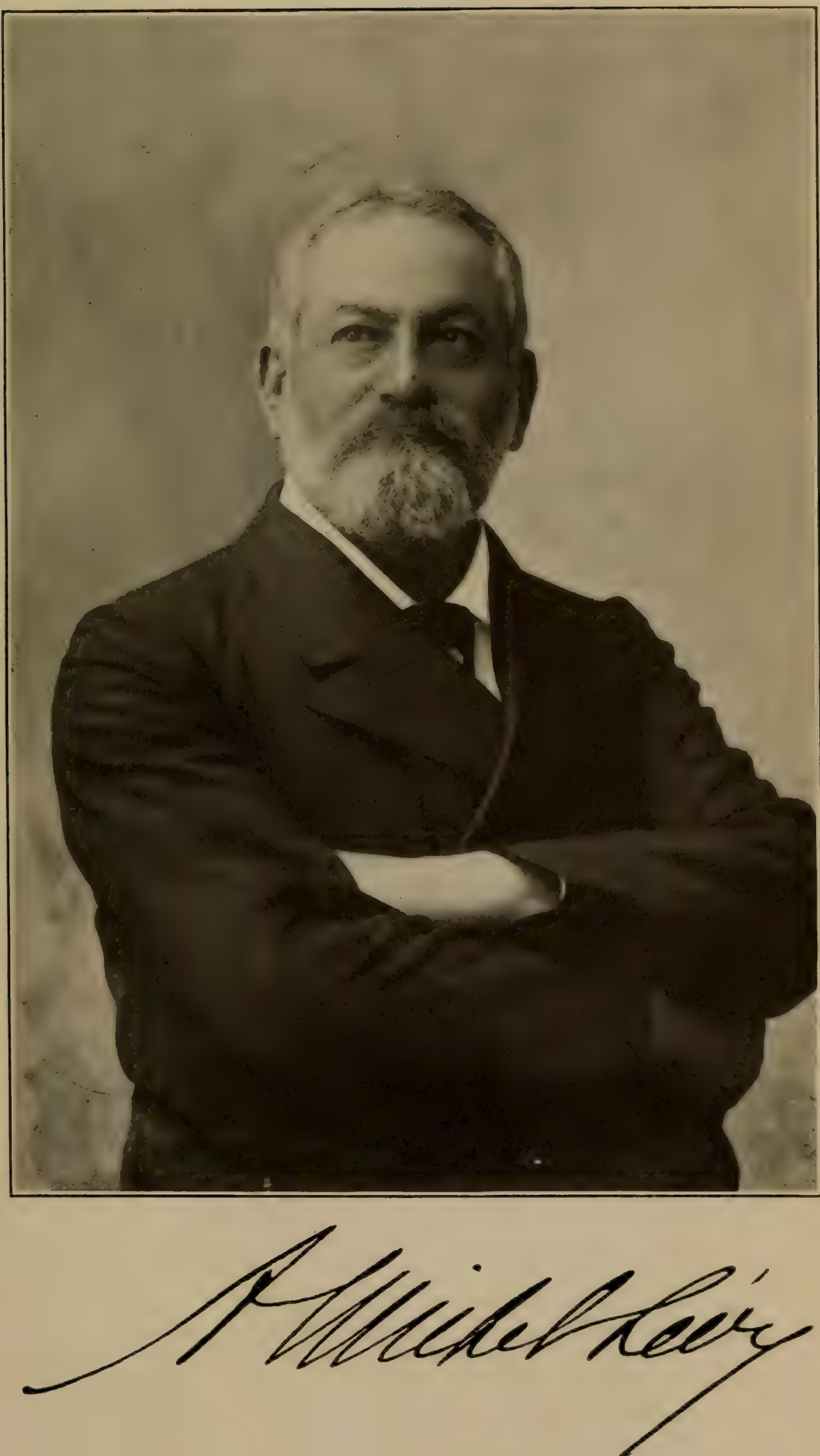
MEMOIR OF AUGUSTE MICHEL-LÉVY

BY ALEXANDER N. WINCHELL

Auguste Michel-Lévy was born in Paris, August 7, 1844, where he died in September, 1911, at the age of 67 years. His father was a physician, who attained distinction as the director of the Medical School of Val-de-Grace. At 20 years of age Michel-Lévy graduated from the École Polytechnique with first honors, and soon afterward entered the government service in the Bureau of Mines (Corps des Mines, Ministère des Travaux Publiques). His advancement in this work was rapid from grade to grade: engineer, inspector, chief inspector, chief engineer, and finally, in 1887, director of the Geological Survey of France (directeur du service de la carte géologique de la France). In 1880 he was in charge of the laboratory of the natural history of inorganic substances at the Collège de France. In 1885 he was selected as a member of a scientific expedition sent to Andalusia by the French Academy of Science.

The published writings of Michel-Lévy show that his attention was directed from the first to geological problems, and that his special interest lay in the study of igneous rocks. His work in areal, stratigraphic, and structural geology is indicated by the fact that he personally prepared ten sheets of the geological map of France on the scale of 1 to 80,000. For this purpose he studied the formations of Morvan, Beaujolais, Charolais, Mont-Dore, Chablais, and some of the most difficult regions of Mont Blanc, and published numerous explanatory memoirs concerning their structure and history. The wide acquaintance with the geology of France obtained through these and other studies and his keen insight into geological problems gave to him an authority, aside from that due to his position, which his colleagues on the French Survey and geologists generally have come to recognize and accept in many difficult problems.

But Michel-Lévy is best known both in France and abroad for his numerous important contributions to mineralogy and petrology. As a mineralogist his writings deal with the zircons of granite, the various forms of crystalline silica, the optical properties of the micas, the synthesis of many rock-forming minerals, the precise measurement of optical properties in thin sections, and especially the precise determination of the plagioclase feldspars by means of microscopic study in polarized light. It is probable that the remarkable advance in the science of petrology resulting from the application of the polarizing microscope to the study



of thin sections in the last century was due more largely to Michel-Lévy than to any other single individual. His contribution to this advance consisted in the study and elucidation of the fundamental laws of light and their relation to crystal structure, the determination of the optical properties and constants of many mineral species, and the invention and description of numerous devices and methods for the accurate measurement of these optical constants. Some of these (for example, the "Tableau des Biréfringences," or colored chart, showing the relation between the interference color, the thickness of the section, and the birefringence of the mineral) are so important that they are in constant use in every petrographic laboratory. Others, such as the stereographic projections of the optical properties of the feldspars, are not so widely used, but are nevertheless extremely valuable for precise determination.

It was in collaboration with the late Professor Fouqué that Michel-Lévy published the monograph on microscopic mineralogy (Minéralogie Micrographique, Paris, 1879), which introduced modern petrography in France; and it was with the same savant that he performed and described numerous remarkable successful experiments in mineral and rock synthesis (Synthèse des Minéraux et des Roches, Paris, 1882). In these experiments the authors produced artificially a large number of minerals and rocks, many of which had never before been synthesized, and established the fact that acid igneous rocks in the presence of water may be fused at a temperature of about 1,000 degrees centigrade, and that basic igneous rocks may be crystallized from dry fusion at about the same temperature.

It was through his wide field experience, his remarkably skillful microscopic work, and his elaborate experiments in rock synthesis that Michel-Lévy developed those theories[1] of petrogenesis that made him a leader of the French school of petrography. It is an irreparable loss to the science of petrology that of the brilliant triumvirate (Fouqué, Michel-Lévy, and Lacroix) who stood as the chief representatives of the French school at the close of the last century, only Lacroix is still living to carry forward the work.

The special combination of qualities which rendered Michel-Lévy famous as a man of science included not only his keen and dispassionate judgment and his wide and varied knowledge of geology, but also his remarkable ability as a mathematician and geometer, which made possible

[1] See especially Structures et Classification des Roches Éruptives, Paris, 1889; Classification des Magmas des Roches Éruptives, Bull. Soc. Geol. Fr., xxv, 1897, pp. 326-377, and xxvi, 1898, pp. 3-19, and numerous articles dealing with special types of rocks, or rocks of special districts, in the Bulletin de la Société Géologique de France, Bulletin des Services de la Carte Géologique de France, and elsewhere.

his elegant mathematical solution of complex problems and the graphic presentation of involved relationships in various kinds of diagrams.

Numerous honors came to him, not only from his countrymen, but also from men of science in all parts of the world. He was a member of the Institute (Academy of Science), an officer of the Legion of Honor, and an honorary member of the Royal Academy of Sciences of Prussia, the Mineralogical Society of Great Britain, the Geological Society of Belgium, the Royal Academy of Dublin, and the Geological Society of London. In 1865 he was awarded the Laplace prize, and, in 1887, the Viquesnel prize of the Geological Society of France; five years later he was elected president of that organization. In 1894 he was made president of the Mineralogical Society of France, and in 1904 he was chosen to succeed Fouqué as professor of the Natural History of Inorganic Substances at the Collège de France. He was elected a correspondent of the Geological Society of America in December, 1910.

It is a pleasure to mention, finally, those qualities which won him the respect and admiration of his associates. He was a man of singular dignity and serenity, combined with a never-failing courtesy and a helpful interest in the work of even the humblest students of geology. In the midst of the many duties of his official work he gave freely of his time and kindly advice to students of geology, mineralogy, and petrography in the various educational institutions of Paris, although until 1904 his only connection with them had been as director of a research laboratory for a short time during the early eighties.

BIBLIOGRAPHY OF W. H. NILES[2]

BY GEORGE H. BARTON

Influence of underlying rocks upon the character of soils upon the tops of certain hills in western Massachusetts. Proceedings of the Boston Society of Natural History, vol. x, 1865, pp. 49-50.

Geological formations of the Burlington limestone. (With C. Wachsmuth.) American Journal of Science and Arts, vol. xlii, 1866, pp. 95-99.

Shells from the "Till" in Boston Harbor and traces of ancient operations in the "Oil" region of Pennsylvania. Proceedings of the Boston Society of Natural History, vol. xii, 1896, pp. 364-366.

Peculiar phenomena observed in quarrying. Proceedings of the Boston Society of Natural History, vol. xiv, 1871, pp. 80-87.

Effect of pressure upon rocks. Proceedings of the Boston Society of Natural History, vol. xv, 1872, pp. 1-2.

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[2] The biography of Professor Niles will be found in volume 22 of the Proceedings of the Society.

Yours truly
Wm. H. Niles.

Some remarks upon the agency of glaciers in the excavation of valleys and lake basins. Proceedings of the Boston Society of Natural History, vol. xv, 1873, pp. 378-381.

Further notice of rock movements at Monson, Massachusetts. Proceedings of the Boston Society of Natural History, vol. xvi, 1873, pp. 41-42.

On some expansions, movements, and fractures of rocks observed at Monson, Massachusetts. Proceedings of the American Association for Advancement of Science, vol. 22, 1873, pp. B156-163.

Physical features of Massachusetts. Proceedings of the Boston Society of Natural History, vol. xvii, 1875, pp. 507-508.

The geological agency of lateral pressure exhibited by certain movements of rocks. Proceedings of the Boston Society of Natural History, vol. xviii, 1876, pp. 272-284.

Upon the relative agency of glaciers and sub-glacial streams in the erosion of valleys. Proceedings of the Boston Society of Natural History, vol. xix, 1878, pp. 330-336.

Upon the occurrence of zones of different physical features upon the slopes of mountains. Proceedings of the Boston Society of Natural History, vol. xix, 1878, pp. 324-330.

The President then called for reports of committees.

REPORT OF THE COMMITTEE ON PHOTOGRAPHS

There has been no change in the collection of photographs belonging to the Society. It is stored in my office in the Bureau of Mines, corner of G and Eighth streets, Washington, where it is accessible to members when I am not in the field.

No additions have been offered during the past year, but new material is acceptable provided it is clearly illustrative of geologic features and of good quality technically.

N. H. DARTON,
Committee.

APPOINTMENT OF COMMITTEE ON CORRESPONDENTSHIP

The Secretary announced that the Council had formed a committee, consisting of W. M. Davis, Arnold Hague, and W. B. Clark, to consider nominations to Correspondentship to be presented to the Society for election at the next annual meeting, and asked that suggestions in writing be made to this committee before Friday noon.

The Society then passed to the reading of papers.

TITLES OF PAPERS AND NAMES OF DISPUTANTS

NEW EVIDENCE ON THE TACONIC QUESTION

BY ARTHUR KEITH

Presented in abstract without manuscript.

SOME FEATURES IN THE GRAND CANYON OF THE COLORADO RIVER

BY N. H. DARTON

Presented in abstract without notes and with lantern slide illustrations.

COVEY HILL REVISITED

BY J. W. SPENCER

Presented in abstract without notes. Discussed by J. B. Woodworth, H. L. Fairchild, and J. W. Spencer.

PRE-CAMBRIAN FORMATIONS IN SOUTH-CENTRAL BRITISH COLUMBIA

BY REGINALD A. DALY

Read in full from manuscript.

GEOLOGICAL RECONNAISSANCE IN NORTHEASTERN NICARAGUA

BY OSCAR H. HERSHEY

Read by title in the absence of the author.

GEOLOGY OF STEEP ROCK LAKE

BY ANDREW C. LAWSON

Read by title in the absence of the author.

ORIGIN OF THE SEDIMENTS AND COLORING MATTER OF THE EASTERN OKLAHOMA RED BEDS

BY J. W. BEEDE

Read in full from manuscript. Discussed by I. C. White.

CORRELATION OF ROCKS IN THE ISOLATED COAL FIELDS AROUND THE SOUTHERN END OF THE ROCKY MOUNTAINS IN NEW MEXICO

BY WILLIS THOMAS LEE

Read in full from manuscript.

MONUMENT CREEK GROUP AND ITS RELATIONS TO THE DENVER AND ARAPAHOE FORMATIONS

BY GEORGE B. RICHARDSON

Read in full from manuscript.

MESOZOIC STRATIGRAPHY OF ALASKA

BY G. C. MARTIN

Read by title in the absence of the author.

DARK SCALE OF HARDNESS

BY ALFRED C. LANE

Presented in abstract from notes.

DEMONSTRATION OF RELATIVE REFRACTION

BY ALFRED C. LANE

Presented in abstract from notes.

STRATIGRAPHIC STUDY OF THE APPALACHIANS AND CENTRAL STATES WITH REFERENCE TO THE OCCURRENCE OF OIL AND GAS

BY GEORGE H. ASHLEY

Presented in abstract from notes. Discussed by H. B. Kümmel.

GRANULARITY LIMITS IN PETROGRAPHIC-MICROSCOPIC WORK

BY FRED. E. WRIGHT

Presented in abstract without notes.

ARKANSAS DIAMOND-BEARING PERIDOTITE AREA

BY L. C. GLENN

Presented in full without notes. Discussed by A. H. Purdue.

NEW MINERALS FROM THE FAVAS OF BRAZIL

BY OLIVER CUMMINGS FARRINGTON

Read by title in the absence of the author.

RESINS IN PALEOZOIC COALS

BY DAVID WHITE

Presented in full without notes.

ONYX DEPOSITS IN EAST TENNESSEE

BY C. H. GORDON

Presented in full without notes.

VARIATION OF THE OPTIC ANGLE OF GYPSUM WITH TEMPERATURE

BY EDWARD H. KRAUS

Presented in full without notes.

PARAGENESIS OF THE ZEOLITES

BY J. VOLNEY LEWIS

Presented in abstract from notes. Discussed by A. C. Lane and F. R. Van Horn, with reply by J. Volney Lewis.

Adjournment was taken at 4.45 o'clock p. m.

Session of Thursday, December 28

The session was called to order at 10.10 o'clock a. m. by President Davis. Special announcements were made by the Secretary, including particularly an invitation from the Director of the Seismological Observatory of Georgetown University to visit the observatory, where there are installed four first-class seismographs.

The Council Report was taken from the table and, on motion, was accepted and ordered printed. It was as follows:

REPORT OF THE COUNCIL

To the Geological Society of America, in twenty-fourth annual meeting assembled:

The regular annual meeting of the Council was held at Pittsburgh, Pennsylvania, in connection with the meeting of the Society, December 27 to 29, 1910. An adjourned meeting was held in New York city on February 25, 1911, and some business has been transacted by correspondence.

The details of administration for the twenty-third year of the existence of the Society are given in the following reports of the officers:

Secretary's Report

To the Council of the Geological Society of America:

Meetings.—The proceedings of the annual meeting of the Society held at Pittsburgh, Pennsylvania, December 27 to 29, 1910, have been recorded in volume 22, pages 1-84, of the Bulletin.

Membership.—During the past year the Society has lost five Fellows by death: Samuel Calvin, Samuel F. Emmons, Christopher W. Hall, Edwin E. Howell, and Amos O. Osborn; and one Correspondent—A. Michel-Lévy. One resignation has become effective, and one Fellow has been dropped for non-payment of dues. The names of the eight Fellows elected at the Pittsburgh meeting have been added to the list, all of them having completed their membership according to rule. The present enrollment of the Society is 320. Twenty-nine candidates are before the

Society for election and several applications are under consideration by Council.

Distribution of Bulletin.—There have been received during the year five new subscriptions to the Bulletin, and one subscriber has dropped from the list, making the present number of subscribers 105. Eight names have been dropped from the exchange list, making the number of exchanges 65. The names of the 6 Correspondents elected at the last meeting of the Society have been added to the mailing list.

The irregular distribution of the Bulletin during the past year has been as follows: Complete volumes sold to the public, 149; sold to Fellows, 2; sent out to supply deficiencies, 2; and delinquents, 1; brochures sent out to supply deficiencies, 21; and delinquents, 61; sold to Fellows, 36; sold to the public, 26.

Bulletin Sales.—The receipts from subscriptions to and sales of the Bulletin during the past year are shown in the following table:

Bulletin Receipts, December 1, 1910–December 1, 1911

	Complete volumes.			Brochures.			Grand total.
	Fellows.	Public.	Total.	Fellows.	Public.	Total.	
Volume 1	....	$15.00	$15.00	$0.25	....	$0.25	$15.25
Volume 2	....	22.50	22.50	....	$0.25	.25	22.75
Volume 3	....	15.00	15.00	....	2.25	2.25	17.25
Volume 4	....	15.00	15.00	....	....	....	15.00
Volume 5	....	15.00	15.00	....	....	....	15.00
Volume 6	....	15.00	15.00	....	2.30	2.30	17.30
Volume 7	....	7.50	7.50	....	1.30	1.30	8.80
Volume 8	....	7.50	7.50	....	.60	.60	8.10
Volume 9	....	7.50	7.50	.35	....	.35	7.85
Volume 10	....	7.50	7.50	.25	....	.25	7.75
Volume 11	....	15.00	15.00	.20	2.60	2.80	17.80
Volume 12	....	7.50	7.50	....	....	....	7.50
Volume 13	....	7.50	7.50	....	1.20	1.20	8.70
Volume 14	....	7.50	7.50	.70	1.60	2.30	9.80
Volume 15	....	7.50	7.50	2.40	....	2.40	9.90
Volume 16	$7.50	15.00	22.50	3.20	.65	3.85	26.35
Volume 17	....	7.50	7.50	1.45	1.45	2.90	10.40
Volume 18	....	5.00	5.00	1.20	4.95	6.15	11.15
Volume 19	....	5.00	5.00	.55	.90	1.45	6.45
Volume 20	....	37.50	37.50	11.10	24.80	35.90	73.40
Volume 21	7.50	112.50	120.00	....	1.15	1.15	121.15
Volume 22	....	700.00	700.00	8.30	18.60	26.90	726.90
Volume 23	....	60.00	60.00	....	....	....	60.00
Total	$15.00	$1,115.00	$1,130.00	$29.95	$64.60	$94.55	$1,224.55
Index 1–10	2.25	4.75	7.00	....	....	....	7.00
Index 11–20	178.50	147.00	325.50	....	....	....	325.50
Total	$195.75	$1,266.75	$1,462.50	$29.95	$64.60	$94.55	$1,557.05

Receipts for the fiscal year		$1,557.05
Previously reported		12,312.56
Total receipts to date		$13,869 61
Charged, but not yet received:	On 1910 account	11.85
	On 1911 account	385.85
Total sales to date		$14,267.31

Sixteen subscriptions to volume 22 are still to be paid for.

Expenses.—The following table gives the cost of administration and of Bulletin distribution during the past year:

EXPENDITURE OF SECRETARY'S OFFICE DURING THE FISCAL YEAR ENDED NOVEMBER 30, 1911

Account of Administration

Postage and telegrams	$73.32	
Express	3.95	
Printing and stationery	89.55	
Membership fee in International Geographical Congress	5.00	
Addressograph plates	.23	
Paleontological Society	20.05	
Total		$192.10

Account of Bulletin

Postage and express	$63.24	
Collection charges on checks	2.04	
Addressograph plates	17.05	
Printing and stationery	1.90	
Canceled subscription returned	7.50	
Binding	10.40	
Reporter of discussions at Pittsburgh meeting	25.00	
Total		127.23
Total expenses for the year		$319.33

Respectfully submitted,

EDMUND OTIS HOVEY,
Secretary.

NEW YORK, *December* 6, 1911.

TREASURER'S REPORT

To the Council of the Geological Society of America:

The Treasurer herewith submits his annual report for the year ending December 1, 1911:

Three (3) Fellows—Arthur Keith, Richard E. Dodge, and N. M. Fenneman—have commuted for life during the year by the payment of

one hundred dollars each, thus increasing the total Life Commutations to one hundred and two (102), which, with four (4) Honorary Life Members, makes a total of one hundred and six (106), of whom ninety-five (95) are now living.

One (1) Fellow is delinquent for four years, and nine (9) Fellows are delinquent for two years, and are therefore liable to be dropped from the roll for non-payment of dues, in accordance with section 3, chapter 1, of the By-Laws; five (5) Fellows are delinquent for the present year, making a total of fifteen (15) delinquents.

The membership of the Society, including delinquents, aggregates at the present time 320, of whom 95 have commuted for life. There have been 5 deaths during the year, 1 resignation, and 1 dropped from the roll. Eight Fellows were elected at the last meeting, all of whom qualified.

With the advice of the Investment Committee, the Treasurer bought during the year a one-thousand-dollar 5 per cent equipment bond of the St. Louis and San Francisco Railroad, at a cost of $1,012.36, and two one-thousand-dollar 5 per cent Fairmount and Clarksburg Traction bonds, at a cost of $2,018.61, including accrued interest in both cases. A St. Louis and San Francisco Railroad equipment 4½ per cent bond purchased earlier was redeemed.

RECEIPTS

Balance in the treasury December 1, 1910		$1,635.89
Fellowship fees, 1907 (1)	$10.00	
1909 (2)	20.00	
1910 (8)	80.00	
1911 (209)	2,090.00	
1912 (3)	30.00	
		2,230.00
Initiation fees (8)		80.00
Life commutations (3)		300.00
Interest on investments:		
Iowa Apartment House Company	$50.00	
Ontario Apartment House Company	......	
Texas and Pacific Railroad bonds	100.00	
U. S. Steel Corporation bonds	150.00	
St. Louis, Iron Mountain and Southern Railroad bond	50.00	
St. Louis and San Francisco Railroad Equipment bond	45.00	
St. Louis and San Francisco Railroad Equipment bond	50.00	
Interest on deposits in Baltimore Trust Company	62.53	
		507.53

Case Library, second payment on purchase	$750.00	
Case Library, for accessions	150.00	
Collection charges added to checks	.60	
Redemption of St. Louis and San Francisco Equipment bond	1,000.00	
Received from Secretary, sales of publications, charges for authors' separates, authors' corrections, etc	1,764.49	
		$8,418.51

EXPENDITURES

Secretary's office:			
Administration	$192.10		
Bulletin	127.23		
Salary	700.00		
		$1,019.33	
Treasurer's office:			
Postage, bond, printing, safe deposit, etc	$49.90		
Allowance for clerical hire	50.00		
		99.90	
Publication of Bulletin:			
Printing[3]	$2,943.03		
Engraving	295.30		
Editor's allowance	250.00		
		3,488.33	
Purchase of St. Louis and San Francisco Equipment 5 per cent bond, including interest		1,012.36	
Purchase of two (2) Fairmount and Clarksburg Traction 5 per cent bonds, including interest		2,018.61	
Balance in bank December 1, 1911		779.98	
			$8,418.51

Respectfully submitted,

WM. BULLOCK CLARK,
Treasurer.

BALTIMORE, MD., *December* 1, 1911.

EDITOR'S REPORT

To the Council of the Geological Society of America:

The Editor submits herewith his annual report.

The following tables cover statistical data for the twenty-two volumes thus far issued:

[3] This item includes the following charges, which have been refunded by the authors:

Authors' separates in excess of number given gratis by the Society	$120.05
Authors' corrections in excess of allowance made by the Society	17.36

Cost.	Average—Vols. 1-20.	Vol. 21.	Vol. 22.
	pp. 610. pls. 55.	pp. 839. pls. 54.	pp. 758. pls. 31.
Letter press	$1,686.58	$2,049.95	$1,660.45
Illustrations	390.99	404.27	260.81
	$2,077.57	$2,454.22	$1,921.26
Average per page	$3.41	$2.93	$2.53

Classification.

Volume.	Areal geology.	Physical geology.	Glacial geology.	Physiographic geology.	Petrographic geology.	Stratigraphic geology.	Paleontologic geology.	Economic geology.	Official matter.	Memorials.	Unclassified.	Total.
	Number of pages.											
1	116	137	92	18	83	44	47	.....	60	4	4	593+xii
2	56	110	60	111	52	168	47	9	55	1	7	662+xiv
3	56	41	44	41	32	158	104	.....	61	15	1	541+xii
4	25	134	38	74	52	52	14	.....	47	32	2	458+xii
5	138	135	70	54	28	51	107	.....	71	14	9	665+xii
6	50	111	75	39	71	99	1	.....	63	25	4	538+x
7	38	77	105	53	40	21	123	4	66	28	13	558+x
8	34	50	98	5	43	67	58	14	79	8	....	446+x
9	2	102	138	.....	44	28	64	16	64	12	....	460+x
10	35	33	96	37	59	62	68	28	84	27	17	534+xii
11	65	110	21	10	54	31	188	7	71	60	46	651+xii
12	199	39	55	53	24	98	5	5	70	2	....	538+xii
13	125	17	13	24	28	116	42	4	165	32	29	583+xii
14	48	47	48	59	183	118	22	1	80	14	1	609+xii
15	26	124	3	94	36	267	.....	.....	77	17	3	636+x
16	64	111	78	30	102	141	19	.....	67	22	15	636+xii
17	49	161	41	84	47	294	27	.....	71	9	2	785+xiv
18	16	164	141	5	29	246	5	.....	68	40	3	717+xii
19	106	108	29	66	30	155	32	.....	56	15	20	617+x
20	43	54	35	29	37	45	303	8	60	3	132	749+xiv
21	72	234	75	48	85	70	106	1	111	11	10	823+xvi
22	23	54	28	28	23	403	74	.....	63	49	1	747+xii

Respectfully submitted,

JOSEPH STANLEY-BROWN, *Editor*.

COLDSPRING HARBOR, N. Y., *December* 15, 1911.

The report of the Auditing Committee was then called for.

REPORT OF THE AUDITING COMMITTEE

The Auditing Committee reported, through its chairman, George P. Merrill, that it had examined the accounts, vouchers, receipts, and bank balances of the Treasurer of the Society and found them correct and in accord with the published statements.[4]

TITLES OF PAPERS AND NAMES OF DISPUTANTS

The reading of scientific papers was then resumed, as follows:

PECULIAR IRON ORE FROM THE DUNHAM MINE, PENNSYLVANIA

BY W. S. BAYLEY

Read in full from manuscript.

GLACIAL DEPOSITS OF THE CONTINENTAL TYPE IN ALASKA

BY R. S. TARR AND LAWRENCE MARTIN

Read in full from manuscript, with lantern slide illustrations. Discussed by W. M. Davis, C. A. Davis, and H. M. Eakin.

GLACIATION IN NORTHWESTERN ALASKA

BY PHILIP S. SMITH

Read in full from manuscript, with lantern slide illustrations.

PRE-WISCONSIN GLACIAL DRIFT IN THE REGION OF GLACIER PARK, MONTANA

BY WILLIAM C. ALDEN

Presented in abstract from notes, with lantern slide illustrations. Discussed by W. W. Atwood and A. P. Coleman, with reply by W. C. Alden.

RESOLUTION CONCERNING THE NAMING OF POWELL NATIONAL PARK

By permission of the Society, the following communication was presented by J. S. Diller:

Some years ago a movement was initiated to erect a memorial to J. W. Powell on the Grand Canyon of the Colorado, which he so bravely ex-

[4] Under date of January 9, 1912, E. B. Mathews reports having examined the Society's securities in the hands of the Treasurer and found them to be as stated in the printed report.

plored. As a result of that movement an appropriation was made by Congress for the purpose, and the matter is being carried out under the advice of a special committee appointed by the Secretary of the Interior.

There is a bill before Congress to make that region a National Park, and the Advisory Committee has addressed the following letter to the Secretary of the Interior concerning the matter:

The Honorable, the Secretary of the Interior.

SIR: Your advisory committee on the John W. Powell Grand Canyon Memorial beg leave to submit for your consideration the suggestion that the proposed park to include a portion of the Grand Canyon of the Colorado be designated "Powell Park of the Grand Canyon."

This designation would be a fitting tribute to the man who risked his life for the sake of revealing to the world the mysteries of one of nature's greatest wonders.

The Grand Canyon of the Colorado is some 300 miles in length. The proposed park will be about 60 miles long, covering 20 per cent of the entire canyon. Other parks or monuments will doubtless be created along other portions of the canyon. The name "Grand Canyon" should be associated with every such feature, but each should bear a separate and distinct name.

The fact that the site selected for the memorial to Major Powell is within the limits of the proposed park affords an additional argument in favor of the appropriateness of this suggested designation.

Very respectfully,

(Signed) CHAS. D. WALCOTT,
W. H. HOLMES,
H. C. RIZER,
Committee.

In view of this proposal of the committee, I move that the Geological Society of America adopt the following resolution:

Resolved, That the Geological Society of America heartily approves naming a national park on the Grand Canyon of the Colorado after its explorer, Major J. W. Powell.

On motion, the resolution was unanimously adopted and the Secretary instructed to transmit it to the Secretary of the Interior.

TITLES OF PAPERS AND NAMES OF DISPUTANTS

The reading of papers was resumed with

SOME GLACIAL DEPOSITS EAST OF CODY, WYOMING, AND THEIR RELATION TO THE PLEISTOCENE EROSIONAL HISTORY OF THE ROCKY MOUNTAIN REGION

BY WILLIAM J. SINCLAIR

Presented in full without notes. Discussed by W. W. Atwood and W. M. Davis.

Then, by unanimous consent of the Society, the following paper was inserted:

FOSSILS OF LOWER LIMESTONE OF STEEP ROCK SERIES

BY CHARLES D. WALCOTT

Presented in abstract from notes. Discussed by A. P. Coleman.

EVIDENCE OF THREE DISTINCT GLACIAL EPOCHS IN THE SAN JUAN MOUNTAINS OF COLORADO

BY WALLACE W. ATWOOD AND KIRTLEY F. MATHER

Presented in full without notes. Discussed by H. E. Gregory.

GLACIAL INVESTIGATIONS IN MINNESOTA IN 1911

BY FRANK LEVERETT

Presented in abstract from notes. Discussed by Lawrence Martin and J. B. Tyrrell.

PRE-WISCONSIN CHANNELS IN SOUTHEASTERN SOUTH DAKOTA AND NORTHEASTERN NEBRASKA

BY J. E. TODD

Read by title in the absence of the author.

RECENT STUDIES OF THE MORAINES OF ONTARIO AND WESTERN NEW YORK

BY FRANK B. TAYLOR

Presented in full without notes. Discussed by W. M. Davis and H. L. Fairchild.

Adjournment was taken at 1.10 o'clock p. m.

The afternoon was devoted to a most interesting visit to the Geophysical Laboratory of the Carnegie Institute by invitation of its Director, Dr. Arthur L. Day.

ANNUAL DINNER

In the evening the Society and its friends, to the number of 238, sat down together at the annual dinner, which was held at the New Ebbitt House. At the close of the dinner, after introductory remarks by President Davis, the management of the evening was turned over to Dr. John

M. Clarke as toastmaster, who called on several of the Fellows to assist him in discharging his duties.

The assembly unanimously voted to send a congratulatory cablegram to Prof. Eduard Suess on account of the celebration of his eightieth birthday. The Secretary prepared and sent the following dispatch: "Geological Society America sends cordial greetings and best wishes." [5]

Session of Friday, December 29

The session of the Society was called to order by President Davis at 9.55 o'clock a. m., and after announcements by the Secretary the reading of papers was resumed.

TITLES OF PAPERS AND NAMES OF DISPUTANTS

GROOVED AND STRIATED CONTACT PLANE BETWEEN THE NEBRASKAN AND KANSAN DRIFTS

BY J. E. CARMAN[6]

Read in full from manuscript.

NEBRASKAN DRIFT OF THE LITTLE SIOUX VALLEY IN NORTHWEST IOWA

BY J. E. CARMAN[6]

Read in full from manuscript. Both papers were discussed by J. W. Spencer, Frank Leverett, and W. M. Davis.

HANGING VALLEYS AND THEIR PRE-GLACIAL EQUIVALENTS IN NEW YORK

BY J. W. SPENCER

Presented in full without notes.

CLOSING PHASE OF GLACIATION IN NEW YORK

BY HERMAN L. FAIRCHILD

Presented in abstract without notes. Discussed by F. B. Taylor and J. W. Spencer, with reply by H. L. Fairchild.

POST-GLACIAL EROSION AND OXIDATION

BY GEORGE FREDERICK WRIGHT

Presented in abstract without notes. Discussed by Frank Leverett, J. W. Spencer, and H. L. Fairchild, with reply by G. F. Wright.

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[5] By return mail the Secretary received a most cordial letter from Professor Suess, expressing his appreciation of the Society's courtesy.

[6] Introduced by George F. Kay.

INTERMINGLING OF PLEISTOCENE FORMATIONS

BY B. SHIMEK

LOESS A LITHOLOGICAL TERM

BY B. SHIMEK

Professor Shimek's two papers were presented without notes. Discussed by W. C. Alden, F. V. Emerson, Frank Leverett, G. F. Wright, with reply by the author.

The Society adjourned at 12.25 o'clock p. m. and reconvened at 2.03 o'clock.

TITLES OF PAPERS AND NAMES OF DISPUTANTS

The first feature of the afternoon session was a symposium on ancient delta deposits, led by Messrs. Barrell, Grabau, and Branson.

CRITERIA FOR THE RECOGNITION OF ANCIENT DELTA DEPOSITS

BY JOSEPH BARRELL

Presented in full without notes.

ANCIENT DELTA DEPOSITS

BY A. W. GRABAU

Presented in full without notes.

MISSISSIPPIAN DELTA IN THE NORTHERN NEW RIVER DISTRICT OF VIRGINIA

BY E. B. BRANSON[7]

Presented in full without notes.

The three last-named papers were discussed by J. M. Clarke, David White, G. W. Stose, Arthur Keith, G. I. Adams, E. T. Wherry, H. B. Kümmel, and W. C. Alden, with reply by Joseph Barrell and A. W. Grabau.

DIFFERENTIAL EROSION AND EQUIPLANATION IN PORTIONS OF YUKON AND ALASKA

BY DE LORME D. CAIRNES[8]

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[7] Introduced by C. F. Marbut.
[8] Introduced by P. E. Raymond.

Presented in abstract without notes. Discussed by W. W. Atwood, W. M. Davis, and H. M. Eakin, with reply by the author.

CENEZOIC HISTORY OF THE WIND RIVER MOUNTAINS, WYOMING

BY L. G. WESTGATE AND E. B. BRANSON

Read in full from manuscript by L. G. Westgate.

GEOGRAPHIC CYCLE IN AN ARID CLIMATE: SHOULD ITS DEVELOPMENT BE BY WIND OR WATER?

BY CHARLES R. KEYES

Read by title in the absence of the author.

STABILITY OF THE ATLANTIC COAST

BY DOUGLAS WILSON JOHNSON

Presented in abstract from notes. Discussed by C. A. Davis, H. B. Kümmel, J. W. Spencer, A. C. Lane, and C. A. Davis.

The Society adjourned at 5 o'clock p. m.

PRESIDENTIAL ADDRESS

In the evening at 8 o'clock, in the lecture hall of the Cosmos Club, Professor Davis read his address as retiring president, entitled "The relations of geography to geology." At the close of the address the members of the Society repaired to the dining-room of the Cosmos Club, where, together with the members of the Paleontological Society and the Association of American Geographers, they were the guests of the Geological Society of Washington at an informal smoker.

Session of Saturday, December 30

The Society convened at 10 o'clock a. m., and, in the absence of the President and Vice-Presidents, A. H. Purdue was elected chairman.

TITLES OF PAPERS AND NAMES OF DISPUTANTS

The reading of papers was resumed, as follows:

PHYSIOGRAPHY OF THE EAST AFRICAN PLATEAU

BY GEORGE LUCIUS COLLIE

Presented in abstract without notes.

EFFECT OF RAPID OFF-SHORE DEEPENING ON LAKE SHORE DEPOSITS

BY RUFUS MATHER BAGG, JR.

Read by title in the absence of the author.

TOYALANÉ: ITS STRUCTURE AND RELATIONS TO OTHER PLATEAU PLAINS OF THE DESERT

BY CHARLES R. KEYES

Read by title in the absence of the author.

PRELIMINARY REPORT OF THE COMMITTEE ON THE NOMENCLATURE OF FAULTS

BY HARRY FIELDING REID

Presented in abstract from notes.

BOULDER-BEDS OF THE CANEY SHALE AT TALAHINA, OKLAHOMA

BY J. B. WOODWORTH

Presented in abstract from notes.

LIST OF UNDERGROUND TEMPERATURES IN THE UNITED STATES

BY N. H. DARTON

Read by title in the absence of the author.

SOME COASTAL MARSHES SOUTH OF CAPE COD

BY CHARLES A. DAVIS

Read in full from manuscript. Discussed by J. B. Woodworth and A. W. Grabau, with reply by the author.

STRUCTURE OF THE HELDERBERG FRONT

BY A. W. GRABAU

Presented in full without notes. Discussed by J. B. Woodworth.

GRAVITY ANOMALIES AND GEOLOGICAL FORMATIONS

BY WILLIAM BOWIE

Read in full from manuscript. Discussed by H. F. Reid, with reply by the author.

In the absence of their authors the following papers were then read by title:

BIBLIOGRAPHY OF MAMMOTH CAVE

BY HORACE C. HOVEY AND R. ELLSWORTH CALL

APPLICATION OF COLOR PHOTOGRAPHY TO OPTICAL MINERALOGY

BY J. HOWARD MATHEWS[9]

COLOR SCHEME FOR CRYSTAL MODELS

BY GEORGE H. CHADWICK

SUGGESTION FOR MINERAL NOMENCLATURE

BY HENRY S. WASHINGTON

OCCURRENCE OF PETROLEUM ASSOCIATED WITH FAULTS AND DIKES

BY FREDERICK G. CLAPP

PROGRESS OF OPINION AS TO THE ORIGIN OF THE IRON ORES OF THE LAKE SUPERIOR REGION

BY N. H. WINCHELL

SAPONITE, THALITE, GREENALITE, AND GREENSTONE

BY N. H. WINCHELL

TWO ARTESIAN WELL RECORDS FROM HATTERAS ISLAND

BY COLLIER COBB

PRE-GLACIAL MIAMI AND KENTUCKY RIVERS

BY N. M. FENNEMAN

STRUCTURE OF ESKER-FANS EXPERIMENTALLY STUDIED

BY T. A. JAGGAR, JR.

GROS VENTRE SLIDE

BY ELIOT BLACKWELDER

RESOLUTION OF THANKS

At the close of the reading of papers, Charles S. Prosser offered a most cordial vote of thanks to the authorities of the National Museum for the

[9] Introduced by A. N. Winchell.

accommodations provided for the holding of the meetings; to the Geological Society of Washington for its hospitality to the Society; to the Cosmos Club for the privileges extended to visiting scientists, and to the local committee (George P. Merrill, chairman; R. S. Bassler, secretary) for the completeness of the preparations that had been made for the comfort of the members and the success of the meeting.

The Society adjourned at 11.50 o'clock a. m.

Register of the Washington Meeting, 1911

FELLOWS

Frank Dawson Adams
George I. Adams
William Clinton Alden
Henry M. Ami
Ralph Arnold
George Hall Ashley
Wallace Walter Atwood
Alfred Ernest Barlow
Joseph Barrell
Ray Smith Bassler
Edson Sunderland Bastin
William S. Bayley
George F. Becker
Joshua W. Beede
Charles P. Berkey
Edward Wilber Berry
Samuel Walker Beyer
Arthur B. Bibbins
Eliot Blackwelder
John Adams Bownocker
Albert Perry Brigham
Reginald W. Brock
Alfred Hulse Brooks
Henry Donald Campbell
Marius R. Campbell
Frank Carney
William Bullock Clark
John Mason Clarke
Herdman F. Cleland
Collier Cobb
Arthur P. Coleman
George L. Collie
Whitman Cross
Edgar R. Cumings
Henry P. Cushing
Reginald A. Daly
Nelson H. Darton
Charles Albert Davis
William M. Davis
Arthur Louis Day
Joseph S. Diller
Edward V. d'Invilliers
Richard E. Dodge
Edwin T. Dumble
Charles R. Eastman
Benjamin K. Emerson
Herman L. Fairchild
Nevin M. Fenneman
August F. Foerste
Russell D. George
L. C. Glenn
Charles H. Gordon
Amadeus W. Grabau
Herbert E. Gregory
Arnold Hague
Baird Halberstadt
Richard R. Hice
Robert T. Hill
Arthur Hollick
Joseph A. Holmes
Edmund Otis Hovey
Ernest Howe
Ellsworth Huntington
Joseph P. Iddings
Thomas Augustus Jaggar, Jr.
Mark S. W. Jefferson
Douglas Wilson Johnson
Arthur Keith
Edward M. Kindle
Frank H. Knowlton
Edward Henry Kraus
Henry B. Kümmel
Alfred C. Lane
Willis Thomas Lee
Frank Leverett
Joseph Volney Lewis

Waldemar Lindgren
Albert P. Low
Richard Swann Lull
Samuel Washington McCallie
W J McGee
Curtis F. Marbut
George Curtis Martin
Lawrence Martin
Edward B. Mathews
W. D. Matthew
Walter C. Mendenhall
George P. Merrill
Arthur M. Miller
Benjamin L. Miller
Willet G. Miller
Malcolm John Munn
Henry Fairfield Osborn
Charles Palache
William A. Parks
Richard A. F. Penrose
George H. Perkins
Joseph Hyde Pratt
Charles S. Prosser
Albert Homer Purdue
Frederick Leslie Ransome
Harry Fielding Reid
William North Rice
George Burr Richardson
Heinrich Ries
Rudolph Ruedemann
Rollin D. Salisbury
William B. Scott
Bohumil Shimek
William John Sinclair
Eugene A. Smith
George Otis Smith
Philip S. Smith
Charles H. Smyth, Jr.
Arthur Coe Spencer
J. W. Spencer
Joseph Stanley-Brown
Timothy William Stanton
George Willis Stose
Charles Kephart Swartz
Ralph S. Tarr
Frank B. Taylor
Joseph B. Tyrrell
Edward O. Ulrich
Frank Robertson Van Horn
Thomas Wayland Vaughan
Charles D. Walcott
Thomas L. Walker
Thomas L. Watson
Stuart Weller
Lewis G. Westgate
David White
Israel C. White
George Reber Wieland
Frank A. Wilder
Henry S. Williams
John E. Wolff
Jay B. Woodworth
Frederic E. Wright
G. Frederick Wright

FELLOWS-ELECT

R. C. Allen
Robert Van Vleck Anderson
Stephen Reid Capps, Jr.
Clarence Norman Fenner
Cyril Workman Knight
Adolf Knopf
Elwood S. Moore
Daniel Webster Ohern
Sidney Paige
Elmer S. Riggs
Joseph T. Singewald, Jr.
Clinton Raymond Stauffer
Lloyd William Stephenson
Mayville William Twitchell

OFFICERS, CORRESPONDENTS, AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS FOR 1912

President:

Herman Leroy Fairchild, Rochester, N. Y.

Vice-Presidents:

Israel C. White, Morgantown, W. Va.
David White, Washington, D. C.

Secretary:

Edmund Otis Hovey, American Museum of Natural History, New York, N. Y.

Treasurer:

Wm. Bullock Clark, Baltimore, Md.

Editor:

J. Stanley-Brown, Coldspring Harbor, Long Island, N. Y.

Librarian:

H. P. Cushing, Cleveland, Ohio

Councillors:

(Term expires 1912)

J. B. Woodworth, Cambridge, Mass.
C. S. Prosser, Columbus, Ohio

(Term expires 1913)

A. H. Purdue, Fayetteville, Ark.
Heinrich Ries, Ithaca, N. Y.

(Term expires 1914)

S. W. Beyer, Ames, Iowa
Arthur Keith, Washington, D. C.

MEMBERSHIP, 1912

CORRESPONDENTS

Charles Barrois, D. ès Sc., D. Sc., Lille, France. December, 1909.
W. C. Brögger, Sc. D., LL. D., Christiania, Norway. December, 1909.
Giovanni Capellini, Bologna, Italy. December, 1910.
Baron Gerhard De Geer, Ph. D., Stockholm, Sweden. December, 1910.
Sir Archibald Geikie, D. C. L., Sc. D., LL. D., Hasslemere, England. December, 1909.
Albert Heim, D. Sc., Zürich, Switzerland. December, 1909.
Emanuel Kayser, Ph. D., Marburg, Germany. December, 1909.
H. Rosenbusch, Ph. D., Heidelberg, Germany. December, 1910.
Eduard Suess, Ph. D., Vienna, Austria. December, 1909.
Emil Tietze, Ph. D., Vienna, Austria. December, 1910.
Th. Tschernyschew, Ph. D., St. Petersburg, Russia. December, 1910.
Ferdinand Zirkel, D. Sc., Ph. D., Bonn, Germany. December, 1909.

FELLOWS

*Indicates Original Fellow (see article III of Constitution)

Cleveland Abbe, Jr., Ph. D., U. S. Weather Bureau, Washington, D. C. August, 1899.
Frank Dawson Adams, Ph. D., McGill University, Montreal, Canada. December, 1889.
George I. Adams, Sc. D., Cosmos Club, Washington, D. C. December, 1902.
José Guadalupe Aguilera, Ph. D., Instituto Geologico, Mexico, Mexico. August, 1896.
William Clinton Alden, A. B., A. M., Ph. D., U. S. Geological Survey, Washington, D. C. December, 1909.
Truman H. Aldrich, M. E., Birmingham, Ala. May, 1889.
R. C. Allen, A. B., A. M., State Geologist, Lansing, Mich. December, 1911.
Henry M. Ami, A. M., Geological and Natural History Survey of Canada, Ottawa, Canada. December, 1889.
Frank M. Anderson, B. A., M. S., State Mining Bureau, 2604 Ætna Street, Berkeley, Cal. June, 1902.
Robert Van Vleck Anderson, A. B., U. S. Geological Survey, Washington, D. C. December, 1911.
Philip Argall, First National Bank Building, Denver, Colo. August, 1896.
Ralph Arnold, Ph. D., 923 Union Oil Bldg., Los Angeles, Cal. December, 1904.
George Hall Ashley, M. E., Ph. D., Capitol Annex, Nashville, Tenn. August, 1895.
Wallace Walter Atwood, B. S., Ph. D., University of Chicago, Chicago, Ill. December, 1909.
Rufus Mather Bagg, Jr., Ph. D., Lawrence College, Appleton, Wis. December, 1896.
Harry Foster Bain, M. S., 667 Howard St., San Francisco, Cal. December, 1895.
Manley Benson Baker, B. A., B. Sc., School of Mining, Kingston, Ontario. December, 1911.

S. Prentiss Baldwin, 2930 Prospect Ave., Cleveland, Ohio. August, 1895.

Sydney H. Ball, A. B., 71 Broadway, New York City. December, 1905.

Erwin Hinckley Barbour, Ph. D., University of Nebraska, Lincoln, Neb. December, 1896.

Alfred Ernest Barlow, B. A., M. A., D. Sc., 328 Roslyn Ave., Westmont, Montreal, Canada. December, 1906.

Joseph Barrell, Ph. D., Yale University, New Haven, Conn. December, 1902.

George H. Barton, B. S., Boston Society of Natural History, Boston, Mass. August, 1890.

Florence Bascom, Ph. D., Bryn Mawr College, Bryn Mawr, Pa. August, 1894.

Ray Smith Bassler, B. A., M. S., Ph. D., U. S. National Museum, Washington, D. C. December, 1906.

Edson Sunderland Bastin, A. B., A. M., A. S., Geological Survey, Washington, D. C. December, 1909.

William S. Bayley, Ph. D., University of Illinois, Urbana, Ill. December, 1888.

*George F. Becker, Ph. D., U. S. Geological Survey, Washington, D. C.

Joshua W. Beede, Ph. D., Indiana University, Bloomington, Ind. December, 1902.

Robert Bell, I. S. O., Sc. D., M. D., LL. D., F. R. S., Geological Survey, Department of Mines, Ottawa, Canada. May, 1889.

Charles P. Berkey, Ph. D., Columbia University, New York, N. Y. Aug., 1901.

Edward Wilber Berry, Johns Hopkins University, Baltimore, Md. December, 1909.

Samuel Walker Beyer, Ph. D., Iowa Agricultural College, Ames, Iowa. December, 1896.

Arthur B. Bibbins, Ph. B., Woman's College, Baltimore, Md. December, 1903.

Albert S. Bickmore, Ph. D., 64th St. and Central Park West, New York, N. Y. December, 1889.

Elliott Blackwelder, A. B., University of Wisconsin, Madison, Wis. December, 1908.

Willis Stanley Blatchley, A. B., A. M., 1530 Park Ave., Indianapolis, Ind. December, 1909.

John M. Boutwell, M. S., 1323 De la Vine St., Santa Barbara, Cal. December, 1905.

John Adams Bownocker, D. Sc., Ohio State University, Columbus, Ohio. December, 1904.

*John C. Branner, Ph. D., Leland Stanford, Jr., University, Stanford University, Cal.

Edwin Bayer Branson, A. B., A. M., Ph. D., University of Missouri, Columbia, Mo. December, 1911.

Albert Perry Brigham, A. B., A. M., Colgate University, Hamilton, N. Y. December, 1893.

Reginald W. Brock, M. A., Geological Survey, Department of Mines, Ottawa, Canada. December, 1904.

Alfred Hulse Brooks, B. S., U. S. Geological Survey, Washington, D. C. August, 1899.

Amos P. Brown, Ph. D., University of Pennsylvania, Philadelphia, Pa. December, 1905.

Barnum Brown, A. B., American Museum of Natural History, New York, N. Y. December, 1910.

Charles Wilson Brown, Ph. B., A. M., Brown University, Providence, R. I. December, 1908.

[8] Ernest Robertson Buckley, Ph. D., Chicago, Ill. June, 1902. June, 1902.

Henry Andrew Buehler, B. S., Rolla, Mo. December, 1909.

G. Montague Butler, E. M., School of Mines, Golden, Colo. December, 1911.

Fred Harvey Hall Calhoun, B. S., Ph. D., Clemson College, S. C. December, 1909.

Henry Donald Campbell, Ph. D., Washington and Lee University, Lexington, Va. May, 1889.

Marius R. Campbell, U. S. Geological Survey, Washington, D. C. August, 1892.

Stephen Reid Capps, Jr., A. B., Ph. D., U. S. Geological Survey, Washington, D. C. December, 1911.

Frank Carney, Ph. D., Denison University, Granville, Ohio. December, 1908.

Ermine C. Case, Ph. D., University of Michigan, Ann Arbor, Mich. December, 1901.

George Halcott Chadwick, Ph. B., M. S., St. Lawrence University, Canton, N. Y. December, 1911.

*T. C. Chamberlin, LL. D., University of Chicago, Chicago, Ill.

Clarence Raymond Claghorn, B. S., M. E., Tacoma, Wash. August, 1891.

Frederick G. Clapp, S. B., 502 Fitzsimons Bldg., Pittsburgh, Pa. December, 1905.

*William Bullock Clark, Ph. D., Johns Hopkins University, Baltimore, Md.

John Mason Clarke, A. M., Ph. D., Albany, N. Y. December, 1897.

Herdman F. Cleland, Ph. D., Williams College, Williamstown, Mass. December, 1905.

J. Morgan Clements, Ph. D., Room 1707, 42 Broadway, New York City. December, 1894.

Collier Cobb, A. B., A. M., University of North Carolina, Chapel Hill, N. C. December, 1894.

Arthur P. Coleman, Ph. D., Toronto University, Toronto, Canada. Dec., 1896.

George L. Collie, Ph. D., Beloit College, Beloit, Wis. December, 1897.

Arthur J. Collier, A. M., S. B., U. S. Geological Survey, Washington, D. C. June, 1902.

*Theodore B. Comstock, Sc. D., 827 Beacon St., Los Angeles, Cal.

Eugene Coste, B. ès Sc., E. H., Toronto, Canada. December, 1906.

Alja Robinson Crook, Ph. D., State Museum of Natural History, Springfield, Ill. December, 1898.

*William O. Crosby, B. S., Massachusetts Institute of Technology, Boston, Mass.

Whitman Cross, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

Garry E. Culver, A. M., 1104 Wisconsin St., Stevens Point, Wis. Dec., 1891.

Edgar R. Cumings, Ph. D., Indiana University, Bloomington, Ind. August, 1901.

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[8] Deceased.

*Henry P. Cushing, M. S., Ph. D., Adelbert College, Cleveland, Ohio.

Reginald A. Daly, Ph. D., Massachusetts Institute of Technology, Boston, Mass. December, 1905.

Edward Salisbury Dana, A. B., A. M., Ph. D., Yale University, New Haven, Conn. December, 1908.

*Nelson H. Darton, U. S. Bureau of Mines, Washington, D. C.

Charles Albert Davis, A. B., A. M., Ph. D., U. S. Bureau of Mines, Washington, D. C. December, 1910.

*William M. Davis, S. B., M. E., Harvard University, Cambridge, Mass.

Arthur Louis Day, B. A., Ph. D., Geophysical Laboratory, Carnegie Institution, Washington, D. C. December, 1909.

David T. Day, Ph. D., U. S. Geological Survey, Washington, D. C. Aug., 1891.

Bashford Dean, A. B., A. M., Ph. D., Columbia University, New York, N. Y. December, 1910.

Orville A. Derby, M. S., Serv. Geol. & Mineral. d'Brazil, Praia Vermillia, Rio de Janeiro, Brazil. December, 1890.

Frank Wilbridge De Wolf, B. S., Urbana, Ill. December, 1909.

*Joseph S. Diller, B. S., U. S. Geological Survey, Washington, D. C.

Edward V. d'Invilliers, E. M., 506 Walnut St., Philadelphia, Pa. Dec., 1888.

Richard E. Dodge, A. M., Teachers' College, New York, N. Y. August, 1897.

Noah Fields Drake, Ph. D., Stanford University, Calif. December, 1898.

John Alexander Dresser, B. A., M. A., Box 72, Sudbury, Ontario, Canada. December, 1906.

Charles R. Dryer, M. A., M. D., Indiana State Normal School, Terre Haute, Ind. August, 1897.

*Edwin T. Dumble, 1306 Main St., Houston, Texas.

[9] Clarence Edward Dutton, A. B., Englewood, N. J. December, 1907.

Arthur S. Eakle, Ph. D., University of California, Berkeley, Cal. Dec., 1899.

Charles R. Eastman, A. M., Ph. D., Carnegie Museum, Pittsburgh, Pa. December, 1895.

Edwin C. Eckel, B. S., C. E., Munsey Building, Washington, D. C. Dec., 1905.

Arthur H. Elftman, Ph. D., P. O. Box 601, Tonopah, Nevada. Dec., 1898.

*Benjamin K. Emerson, Ph. D., Amherst College, Amherst, Mass.

John Eyerman, F. Z. S., Oakhurst, Easton, Pa. August, 1891.

Harold W. Fairbanks, B. S., Berkeley, Cal. August, 1892.

*Herman L. Fairchild, B. S., University of Rochester, Rochester, N. Y.

Oliver C. Farrington, Ph. D., Field Museum of Natural History, Chicago, Ill. December, 1895.

Nevin M. Fenneman, Ph. D., University of Cincinnati, Cincinnati, Ohio. December, 1904.

Clarence Norman Fenner, E. M., A. M., Ph. D., Geophysical Laboratory, Washington, D. C. December, 1911.

Cassius Asa Fisher, A. B., A. M., 711 Ideal Bldg., Denver, Colo. Dec., 1908.

August F. Foerste, Ph. D., Steele High School, Dayton, Ohio. Dec., 1899.

William M. Fontaine, A. M., University of Virginia, Charlottesville, Va. December, 1888.

Myron Leslie Fuller, S. B., 104 Belmont Ave., Brockton, Mass. Dec., 1898.

Henry Stewart Gane, Ph. D., Santa Barbara, Cal. December, 1896.

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[9] Deceased.

James H. Gardner, M. S., Ph. D., Kentucky Geological Survey, Lexington, Ky. December, 1911.

Russell D. George, A. B., A. M., University of Colorado, Boulder, Colo. December, 1906.

*Grove K. Gilbert, A. M., LL. D., U. S. Geological Survey, Washington, D. C.

Adam Capen Gill, Ph. D., Cornell University, Ithaca, N. Y. December, 1888.

L. C. Glenn, Ph. D., Vanderbilt University, Nashville, Tenn. June, 1900.

James Walter Goldthwait, A. B., A. M., Ph. D., Dartmouth College, Hanover, N. H. December, 1909.

Charles H. Gordon, Ph. D., University of Tennessee, Knoxville, Tenn. August, 1893.

Charles Newton Gould, A. M., University of Oklahoma, Norman, Okla. December, 1904.

Amadeus W. Grabau, M. S., S. D., Columbia University, New York, N. Y. December, 1898.

Walter Granger, American Museum of Natural History, New York, N. Y. December, 1911.

Ulysses Sherman Grant, Ph. D., Northwestern University, Evanston, Ill. December, 1890.

John Sharshall Grasty, A. B., Ph.D., University of Virginia, University, Va. December, 1911.

Herbert E. Gregory, Ph. D., Yale University, New Haven, Conn. Aug., 1901.

George P. Grimsley, Ph. D., Geological Survey of West Virginia, Martinsburg, W. Va. August, 1895.

Leon S. Griswold, A. B., Plymouth, Mass. August, 1902.

Frederic P. Gulliver, Ph. D., Norwichtown, Conn. August, 1895.

Arnold Hague, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

Baird Halberstadt, Pottsville, Pa. December, 1909.

Gilbert D. Harris, Ph. B., Cornell University, Ithaca, N. Y. December, 1903.

John Burchmore Harrison, M. A., F. I. C., F. G. S., Georgetown, British Guiana. June, 1902.

John B. Hastings, M. E., 1480 High St., Denver, Colo. May, 1889.

*Erasmus Haworth, Ph. D., University of Kansas, Lawrence, Kans.

C. Willard Hayes, Ph. D., Compania Mexicana de Petroleo "El Aguila," Tampico, Mexico. May, 1889.

Oscar H. Hershey, Kellogg, Idaho. December, 1909.

Richard R. Hice, B. S., Beaver, Pa. December, 1903.

Frank A. Hill, Roanoke, Va. May, 1889.

*Robert T. Hill, B. S., 25 Broad St., New York, N. Y.

Richard C. Hills, Denver, Colo. August, 1894.

*Charles H. Hitchcock, Ph. D., LL. D., Honolulu, Hawaiian Islands.

William Herbert Hobbs, Ph. D., University of Michigan, Ann Arbor, Mich. August, 1891.

*Levi Holbrook, A. M., P. O. Box 536, New York, N. Y.

William Jacob Holland, A. B., A. M., Carnegie Museum, Pittsburgh, Pa. December, 1910.

Arthur Hollick, Ph. D., New York Botanical Garden, Bronx Park, New York City. August, 1893.

*Joseph A. Holmes, U. S. Bureau of Mines, Washington, D. C.

Thomas C. Hopkins, Ph. D., Syracuse University, Syracuse, N. Y. Dec., 1894.

William Otis Hotchkiss, B. S., C. E., State Geologist, Madison, Wis. December, 1911.

*Edmund Otis Hovey, A. B., Ph. D., American Museum of Natural History, New York, N. Y.

*Horace C. Hovey, D. D., Newburyport, Mass.

Ernest Howe, Ph. D., 75 Kay St., Newport, R. I. December, 1903.

Lucius L. Hubbard, Ph. D., LL. D., Houghton, Mich. December, 1894.

Ellsworth Huntington, A. B., A. M., Yale University, New Haven, Conn. December, 1906.

Louis Hussakof, B. S., Ph. D., American Museum of Natural History, New York, N. Y. December, 1910.

Joseph P. Iddings, Ph. B., Brinklow, Md. May, 1889.

John D. Irving, Ph. D., Yale University, New Haven, Conn. December, 1905.

A. Wendell Jackson, Ph. B., 432 Saint Nicholas Ave., New York, N. Y. December, 1888.

Robert T. Jackson, S. D., 56 Bay State Road, Boston, Mass. August, 1894.

[10] Thomas M. Jackson, C. E., S. D., Clarksburg, W. Va. May, 1889.
of Technology, Boston, Mass. December, 1906.

Mark S. W. Jefferson, A. M., Michigan State Normal College, Ypsilanti, Mich. December, 1904.

Albert Johannsen, B. S., Ph. D., University of Chicago, Chicago, Ill. December, 1908.

Douglas Wilson Johnson, B. S., Ph. D., Harvard University, Cambridge, Mass. December, 1906.

Alexis A. Julien, Ph. D., South Harwich, Mass. May, 1889.

George Frederick Kay, M. A., State University of Iowa, Iowa City, Iowa. December, 1908.

Arthur Keith, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.

*James F. Kemp, A. B., E. M., Columbia University, New York, N. Y.

Charles Rollin Keyes, Ph. D., 944 Fifth St., Des Moines, Iowa. Aug., 1890.

Edward M. Kindle, Ph. D., U. S. Geological Survey, Washington, D. C. December, 1905.

Cyril Workman Knight, B. S., Toronto, Ontario, Canada. December, 1911.

Adolph Knopf, B. S., M. S., Ph. D., U. S. Geological Survey, Washington, D. C. December, 1911.

Frank H. Knowlton, M. S., U. S. National Museum, Washington, D. C. May, 1889.

Edward Henry Kraus, Ph. D., University of Michigan, Ann Arbor, Mich. June, 1902.

Henry B. Kümmel, Ph. D., Trenton, N. J. December, 1895.

*George F. Kunz, A. M. (Hon.), Ph. D. (Hon.), care of Tiffany & Co., Fifth Ave., at 37th St., New York, N. Y.

George Edgar Ladd, Ph. D., Wilburton, Okla. August, 1891.

Lawrence Morris Lambe, Department of Mines, Ottawa, Canada. December, 1911.

Henry Landes, A. B., A. M., University of Washington, University Station, Seattle, Wash. December, 1908.

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[10] Deceased.

Alfred C. Lane, Ph. D., Tufts College, Mass. December, 1889.

Andrew C. Lawson, Ph. D., University of California, Berkeley, Cal. May, 1889.

Willis Thomas Lee, M. S., U. S. Geological Survey, Washington, D. C. December, 1903.

Charles K. Leith, Ph. D., University of Wisconsin, Madison, Wis. December, 1902.

Arthur G. Leonard, Ph. D., State University of North Dakota, Grand Forks, N. Dak. December, 1901.

Frank Leverett, B. S., Ann Arbor, Mich. August, 1890.

Joseph Volney Lewis, B. E., S. B., Rutgers College, New Brunswick, N. J. December, 1906.

William Libbey, Sc. D., Princeton University, Princeton, N. J. August, 1899.

Waldemar Lindgren, M. E., U. S. Geological Survey, Washington, D. C. August, 1890.

Frederick Brewster Loomis, B. A., Ph. D., Amherst College, Amherst, Mass. December, 1909.

George Davis Louderback, Ph. D., University of California, Berkeley, Cal. June, 1902.

Robert H. Loughridge, Ph. D., University of California, Berkeley, Cal. May, 1889.

Albert P. Low, B. A., Sc. D., LL. D., Deputy Minister, Department of Mines, Ottawa, Canada. December, 1905.

Richard Swann Lull, B. S., M. S., Ph. D., Yale University, New Haven, Conn. December, 1909.

Samuel Washington McCallie, Ph. B., Atlanta, Ga. December, 1909.

Hiram Deyer McCaskey, B. S., U. S. Geological Survey, Washington, D. C. December, 1904.

Richard G. McConnell, A. B., Geological and Natural History Survey of Canada, Ottawa, Canada. May, 1889.

James Rieman Macfarlane, A. B., Woodland Road, Pittsburgh, Pa. August, 1891.

*W J McGee, LL. D., Inland Waterways Commission, Washington, D. C.

William McInnes, A. B., Geological and Natural History Survey of Canada, Ottawa, Canada. May, 1889.

Peter McKellar, Fort William, Ontario, Canada. August, 1890.

George Rogers Mansfield, B. S., A. M., Ph. D., Northwestern University, Evanston, Ill. December, 1909.

Curtis F. Marbut, A. M., State University, Columbia, Mo. August, 1897.

Vernon F. Marsters, A. M., Apartado 856, Lima, Peru. August, 1892.

George Curtis Martin, Ph. D., U. S. Geological Survey, Washington, D. C. June, 1902.

Lawrence Martin, A. B., A. M., University of Wisconsin, Madison, Wis. December, 1909.

Edward B. Mathews, Ph. D., Johns Hopkins University, Baltimore, Md. August, 1895.

W. D. Matthew, Ph. D., American Museum of Natural History, New York, N. Y. December, 1903.

P. H. Mell, M. E., Ph. D., 165 East 10th St., Atlanta, Ga. December, 1888.

Walter C. Mendenhall, B. S., U. S. Geological Survey, Washington, D. C. June, 1902.

John C. Merriam, Ph. D., University of California, Berkeley, Cal. Aug., 1895.

*Frederick J. H. Merrill, Ph. D., 624 Citizens' National Bank Building, Los Angeles, Calif.

George P. Merrill, Ph. D., U. S. National Museum, Washington, D. C. December, 1888.

Arthur M. Miller, A. M., State University of Kentucky, Lexington, Ky. December, 1897.

Benjamin L. Miller, Ph. D., Lehigh University, South Bethlehem, Pa. December, 1904.

Willet G. Miller, M. A., Toronto, Canada. December, 1902.

William John Miller, S. B., Ph. D., Hamilton College, Clinton, N. Y. December, 1909.

Henry Montgomery, Ph. D., University of Toronto, Toronto, Canada. December, 1904.

Elwood S. Moore, B. A., M. A., Ph. D., Pennsylvania State College, State College, Pa. December, 1911.

Malcolm John Munn, U. S. Geological Survey, Washington, D. C. Dec., 1909.

*Frank L. Nason, A. B., West Haven, Conn.

David Hale Newland, B. A., Albany, N. Y. December, 1906.

John F. Newsom, Ph. D., Leland Stanford, Jr., University, Stanford University, Cal. December, 1899.

William H. Norton, M. A., Cornell College, Mount Vernon, Iowa. Dec., 1895.

Charles J. Norwood, State University, Lexington, Ky. August, 1894.

Ida Helen Ogilvie, A. B., Ph. D., Barnard College, Columbia University, New York, N. Y. December, 1906.

Cleophas C. O'Harra, Ph. D., South Dakota School of Mines, Rapid City, S. Dak. December, 1904.

Daniel Webster Ohern, A. B., A. M., Ph. D., University of Oklahoma, Norman, Okla. December, 1911.

Ezequiel Ordonez, 2 a General Prine, Mexico, D. F., Mex. August, 1896.

Edward Orton, Jr., E. M., Geological Survey of Ohio, Columbus, Ohio. December, 1909.

Henry F. Osborn, Sc. D., American Museum of Natural History, New York, N. Y. August, 1894.

Sidney Paige, U. S. Geological Survey, Washington, D. C. December, 1911.

Charles Palache, B. S., Harvard University, Cambridge, Mass. Aug., 1897.

William A. Parks, B. A., Ph. D., University of Toronto, Toronto, Canada. December, 1906.

*Horace B. Patton, Ph. D., Colorado School of Mines, Golden, Colo.

Frederick B. Peck, Ph. D., Lafayette College, Easton, Pa. August, 1901.

Richard A. F. Penrose, Jr., Ph. D., 460 Bullitt Building, Philadelphia, Pa. May, 1889.

George H. Perkins, Ph. D., University of Vermont, Burlington, Vt.; State Geologist. June, 1902.

Joseph H. Perry, 276 Highland St., Worcester, Mass. December, 1888.

Olaf August Peterson, Carnegie Museum, Pittsburgh, Pa. December, 1910.

Louis V. Pirsson, Ph. D., Sheffield Scientific School, Yale University, New Haven, Conn. August, 1894.

JOSEPH E. POGUE, A. B., M. S., Ph. D., U. S. National Museum, Washington, D. C. December, 1911.

JOSEPH HYDE PRATT, Ph. D., North Carolina Geological Survey, Chapel Hill, N. C. December, 1898.

*CHARLES S. PROSSER, D. Sc., Ph. D., Ohio State University, Columbus, Ohio.

WILLIAM FREDERICK PROUTY, B. S., M. S., Ph. D., University of Alabama, University, Ala. December, 1911.

*RAPHAEL PUMPELLY, Newport, R. I.

ALBERT HOMER PURDUE, B. A., State Geological Survey, Nashville, Tenn. December, 1904.

FREDERICK LESLIE RANSOME, Ph. D., U. S. Geological Survey, Washington, D. C. August, 1895.

PERCY EDWARD RAYMOND, B. A., Ph. D., Museum of Comparative Zoölogy, Cambridge, Mass. December, 1907.

HARRY FIELDING REID, Ph. D., Johns Hopkins University, Baltimore, Md. December, 1892.

WILLIAM NORTH RICE, Ph. D., LL. D., Wesleyan University, Middletown, Conn. August, 1890.

CHARLES H. RICHARDSON, Ph. D., Syracuse University, Syracuse, N. Y. December, 1899.

GEORGE BURR RICHARDSON, S. B., S. M., Ph. D., U. S. Geological Survey, Washington, D. C. December, 1908.

HEINRICH RIES, Ph. D., Cornell University, Ithaca, N. Y. December, 1893.

ELMER S. RIGGS, A. B., A. M., Field Museum of Natural History, Chicago, Ill. December, 1911.

JESSE PERRY ROWE, B. S., M. A., Ph. D., University of Montana, Missoula, Mont. December, 1911.

RUDOLPH RUEDEMANN, Ph. D., Albany, N. Y. December, 1905.

JOHN JOSEPH RUTLEDGE, B. Sc., Ph. D., U. S. Bureau of Mines, Knoxville, Tenn. December, 1911.

ORESTES H. ST. JOHN, 1141 Twelfth St., San Diego, Cal. May, 1889.

*ROLLIN D. SALISBURY, A. M., University of Chicago, Chicago, Ill.

FREDERICK W. SARDESON, Ph. D., University of Minnesota, Minneapolis, Minn. December, 1892.

THOMAS EDMUND SAVAGE, A. B., B. S., M. S., University of Illinois, Urbana, Ill. December, 1907.

FRANK C. SCHRADER, M. S., A. M., U. S. Geological Survey, Washington, D. C. August, 1901.

CHARLES SCHUCHERT, Yale University, New Haven, Conn. August, 1895.

WILLIAM B. SCOTT, Ph. D., Princeton University, Princeton, N. J. Aug., 1892.

ARTHUR EDMUND SEAMAN, B. S., Michigan College of Mines, Houghton, Mich. December, 1904.

HENRY M. SEELY, M. D., Middlebury College, Middlebury, Vt. May, 1889.

ELIAS H. SELLARDS, Ph. D., Tallahassee, Fla. December, 1905.

JOAQUIM CANDIDO DA COSTA SEÑA, State School of Mines, Ouro Preto, Brazil. December, 1908.

GEORGE BURBANK SHATTUCK, Ph. D., Vassar College, Poughkeepsie, N. Y. August, 1899.

SOLON SHEDD, A. B., Washington Agricultural College, Pullman, Wash. December, 1904.

Edward M. Shepard, Sc. D., 1403 Benton Ave., Springfield, Mo. August, 1901.

Will H. Sherzer, M. S., State Normal School, Ypsilanti, Mich. Dec., 1890.

Bohumil Shimek, C. E., M. S., University of Iowa, Iowa City, Iowa. December, 1904.

Hervey Woodburn Shimer, A. B., A. M., Ph. D., Massachusetts Institute of Technology, Boston, Mass. December, 1910.

Frederick W. Simonds, Ph. D., University of Texas, Austin, Texas.

William John Sinclair, B. S., Ph. D., Princeton University, Princeton, N. J. December, 1906.

Joseph Theophilus Singewald, A. B., Ph. D., Johns Hopkins University, Baltimore, Md. December, 1911.

Earle Sloan, Charleston, S. C. December, 1908.

Burnett Smith, B. S., Ph. D., Syracuse University, Skaneateles, N. Y. December, 1911.

*Eugene A. Smith, Ph. D., University of Alabama, University, Ala.

George Otis Smith, Ph. D., U. S. Geological Survey, Washington, D. C. August, 1897.

Philip S. Smith, A. B., A. M., Ph. D., U. S. Geological Survey, Washington, D. C. December, 1909.

Warren Du Pré Smith, B. S., A. M., Ph. D., Mining Bureau, Manila, Philippine Islands. December, 1909.

W. S. Tangier Smith, Ph. D., University of Nevada, Reno, Nev. June, 1902.

*John C. Smock, Ph. D., Trenton, N. J.

Charles H. Smyth, Jr., Ph. D., Princeton University, Princeton, N. J. August, 1892.

Henry L. Smyth, A. B., Harvard University, Cambridge, Mass. Aug., 1894.

Arthur Coe Spencer, B. S., Ph. D., U. S. Geological Survey, Washington, D. C. December, 1896.

*J. W. Spencer, Ph. D., 2019 Hillyer Place, Washington, D. C.

Frank Springer, Ph. B., U. S. National Museum, Washington, D. C. December, 1911.

Josiah E. Spurr, A. B., A. M., 165 Broadway, New York, N. Y. Dec., 1894.

Joseph Stanley-Brown, Coldspring Harbor, Long Island, N. Y. Aug., 1892.

Timothy William Stanton, B. S., U. S. National Museum, Washington, D. C. August, 1891.

Clinton Raymond Stauffer, B. S., M. S., Ph. D., Western Reserve University, Cleveland, Ohio. December, 1911.

Lloyd William Stephenson, Ph. B., Ph. D., U. S. Geological Survey, Washington, D. C. December, 1911.

*John J. Stevenson, Ph. D., LL. D., 568 West End Ave., New York, N. Y.

George Willis Stose, B. S., U. S. Geological Survey, Washington, D. C. December, 1908.

William J. Sutton, B. S., E. M., Victoria, B. C. August, 1901.

Charles Kephart Swartz, A. B., Ph. D., Johns Hopkins University, Baltimore, Md. December, 1908.

Joseph A. Taff, B. S., 1076 Flood Bldg., San Francisco, Cal. August, 1895.

James E. Talmage, Ph. D., University of Utah, Salt Lake City, Utah. December, 1897.

Ralph S. Tarr, Cornell University, Ithaca, N. Y. August, 1890.

Frank B. Taylor, Fort Wayne, Ind. December, 1895.

*James E. Todd, A. M., 1224 Rhode Island St., Lawrence, Kas.

Cyrus Fisher Tolman, Jr., B. S., University of Arizona, Tucson, Ariz. December, 1909.

*Henry W. Turner, B. S., Room 709, Mills Building, San Francisco, Cal.

Mayville William Twitchell, B. S., M. S., Ph. D., University of South Carolina, Columbia, S. C. December, 1911.

Joseph B. Tyrrell, M. A., B. Sc., Room 534, Confederation Life Building, Toronto, Canada. May, 1889.

Johan A. Udden, A. M., Augustana College, Rock Island, Ill. August, 1897.

Edward O. Ulrich, D. Sc., U. S. Geological Survey, Washington, D. C. December, 1903.

*Warren Upham, A. M., Minnesota Historical Society, Saint Paul, Minn.

*Charles R. Van Hise, M. S., Ph. D., University of Wisconsin, Madison, Wis.

Frank Robertson Van Horn, Ph. D., Case School of Applied Science, Cleveland, Ohio. December, 1898.

Gilbert van Ingen, Princeton University, Princeton, N. J. December, 1904.

Thomas Wayland Vaughan, B. S., A. M., U. S. Geological Survey, Washington, D. C. August, 1896.

Arthur Clifford Veach, 3415 Ashley Terrace, Washington, D. C. December, 1906.

*Anthony W. Vogdes, 2425 First St., San Diego, Cal.

*M. Edward Wadsworth, Ph. D., School of Mines, University of Pittsburgh, Pittsburgh, Pa.

*Charles D. Walcott, LL. D., Smithsonian Institution, Washington, D. C.

Thomas L. Walker, Ph. D., University of Toronto, Toronto, Canada. December, 1903.

Charles H. Warren, Ph. D., Massachusetts Institute of Technology, Boston, Mass. December, 1901.

Henry Stephens Washington, Ph. D., Locust, Monmouth Co., N. J. August, 1896.

Thomas L. Watson, Ph. D., University of Virginia, Charlottesville, Va. June, 1900.

Walter H. Weed, E. M., Norwalk, Conn. May, 1889.

Samuel Weidman, Ph. D., Wisconsin Geological and Natural History Survey, Madison, Wis. December, 1903.

Stuart Weller, B. S., University of Chicago, Chicago, Ill. June, 1900.

Lewis G. Westgate, Ph. D., Ohio Wesleyan University, Delaware, Ohio.

David White, B. S., U. S. National Museum, Washington, D. C. May, 1889.

*Israel C. White, Ph. D., Morgantown, W. Va.

George Reber Wieland, B. S., Ph. D., Yale University, New Haven, Conn. December, 1910.

Frank A. Wilder, Ph. D., North Holston, Smyth Co., Va. December, 1905.

*Edward H. Williams, Jr., A. B., E. M., Woodstock, Vt.

*Henry S. Williams, Ph. D., Cornell University, Ithaca, N. Y.

Ira A. Williams, M. Sc., Iowa State College, Ames, Iowa. December, 1905.

Bailey Willis, U. S. Geological Survey, Washington, D. C. December, 1889.

Samuel W. Williston, Ph. D., M. D., University of Chicago, Chicago, Ill. December, 1889.

Arthur B. Wilmott, M. A., 404 Lumsden Building, Toronto, Canada. December, 1899.

ALFRED W. G. WILSON, Ph. D., Mines Branch, Department of Mines, Ottawa, Canada. June, 1902.

ALEXANDER N. WINCHELL, Doct. U. Paris, University of Wisconsin, Madison, Wis. August, 1901.

*HORACE VAUGHN WINCHELL, 505 Palace Building, Minneapolis, Minn.

*NEWTON H. WINCHELL, A. M., 501 East River Road, Minneapolis, Minn.

*ARTHUR WINSLOW, B. S., 131 State St., Boston, Mass.

JOHN E. WOLFF, Ph. D., Harvard University, Cambridge, Mass. Dec., 1889.

JOSEPH E. WOODMAN, S. D., New York University, New York, N. Y. Dec., 1905.

ROBERT S. WOODWARD, C. E., Carnegie Institution of Washington, Washington, D. C. May, 1889.

JAY B. WOODWORTH, B. S., Harvard University, Cambridge, Mass. Dec., 1895.

CHARLES WILL WRIGHT, B. S., M. E., Ingurtosu, Arbus, Sardinia, Italy. December, 1909.

FREDERIC E. WRIGHT, Ph. D., Geophysical Laboratory, Carnegie Institution, Washington, D. C. December, 1903.

*G. FREDERICK WRIGHT, D. D., Oberlin Theological Seminary, Oberlin, Ohio.

GEORGE A. YOUNG, Ph. D., Geological Survey of Canada, Ottawa, Canada. December, 1905.

CORRESPONDENT DECEASED

A. MICHEL-LÉVY. Died September, 1911.

FELLOWS DECEASED

***Indicates Original Fellow (see article III of Constitution)**

*CHARLES A. ASHBURNER, M. S., C. E. Died December 24, 1889.
CHARLES E. BEECHER, Ph. D. Died February 14, 1904.
WILLIAM PHIPPS BLAKE. Died May 21, 1910.
AMOS BOWMAN. Died June 18, 1894.
*SAMUEL CALVIN, Ph. D., LL. D. Died April 17, 1911.
FRANKLIN R. CARPENTER. Died April 1, 1910.
*J. H. CHAPIN, Ph. D. Died March 14, 1892.
*EDWARD W. CLAYPOLE, D. Sc. Died August 17, 1901.
GEORGE H. COOK, Ph. D., LL. D. Died September 22, 1889.
*EDWARD D. COPE, Ph. D. Died April 12, 1897.
ANTONIO DEL CASTILLO. Died October 28, 1895.
*JAMES D. DANA, LL. D. Died April 14, 1895.
GEORGE M. DAWSON, D. Sc. Died March 2, 1901.
Sir J. WILLIAM DAWSON, LL. D. Died November 19, 1899.
*WILLIAM B. DWIGHT, Ph. B. Died August 29, 1906.
*GEORGE H. ELDRIDGE, A. B. Died June 29, 1905.
*SAMUEL F. EMMONS, A. M., E. M. Died March 28, 1911.
*ALBERT E. FOOTE. Died October 10, 1895.
*PERSIFOR FRAZER. Died April 7, 1909.
*HOMER T. FULLER. Died August 14, 1908.
N. J. GIROUX, C. E. Died November 30, 1890.
*CHRISTOPHER W. HALL, A. M. Died May 10, 1911.
*JAMES HALL, LL. D. Died August 7, 1898.
JOHN B. HATCHER, Ph. B. Died July 3, 1904.
*ROBERT HAY. Died December 14, 1895.

*Angelo Heilprin. Died July 17, 1907.
David Honeyman, D. C. L. Died October 17, 1889.
*Edwin E. Howell, A. M. Died April 16, 1911.
Thomas Sterry Hunt, D. Sc., LL. D. Died February 12, 1892.
*Alpheus Hyatt, B. S. Died January 15, 1902.
*Joseph F. James, M. S. Died March 29, 1897.
Wilbur C. Knight, B. S., A. M. Died July 28, 1903.
Ralph D. Lacoe. Died February 5, 1901.
J. C. K. Laflamme. Died July 6, 1910.
Daniel W. Langton. Died June 21, 1909.
*Joseph Le Conte, M. D., LL. D. Died July 6, 1901.
*J. Peter Lesley, LL. D. Died June 2, 1903.
Henry McCalley, A. M., C. E. Died November 20, 1904.
Oliver Marcy, LL. D. Died March 19, 1899.
Othniel C. Marsh, Ph. D., LL. D. Died March 18, 1899.
James E. Mills, B. S. Died July 25, 1901.
*Henry B. Nason, M. D., Ph. D., LL. D. Died January 17, 1895.
*Peter Neff, M. A. Died May 11, 1903.
*John S. Newberry, M. D., LL. D. Died December 7, 1892.
William H. Niles. Died September 12, 1910.
*Edward Orton, Ph. D., LL. D. Died October 16, 1899.
*Amos O. Osborn. Died March, 1911.
*Richard Owen, LL. D. Died March 24, 1890.
Samuel L. Penfield. Died August 14, 1906.
David Pearce Penhallow. Died October 20, 1910.
*Franklin Platt. Died July 24, 1900.
William H. Pettee, A. M. Died May 26, 1904.
*John Wesley Powell, LL. D. Died September 23, 1902.
*Israel C. Russell, LL. D. Died May 1, 1906.
*James M. Safford, M. D., LL. D. Died July 3, 1907.
*Charles Schaeffer, M. D. Died November 23, 1903.
*Nathaniel S. Shaler, LL. D. Died April 10, 1906.
William G. Tight, A. M., Ph. D. Died January 15, 1910.
Charles Wachsmuth. Died February 7, 1896.
Thomas C. Weston. Died July 20, 1910.
Theodore G. White, Ph. D. Died July 7, 1901.
*George H. Williams, Ph. D. Died July 12, 1894.
*Robert P. Whitfield, A. M. Died April 6, 1910.
*J. Francis Williams, Ph. D. Died September 9, 1891.
*Alexander Winchell, LL. D. Died February 19, 1891.
Albert A. Wright, Ph. D. Died April 2, 1905.
William S. Yeates. Died February 19, 1908.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

VOL. 23, PP. 69-76 MARCH 14, 1912

PROCEEDINGS OF THE TWELFTH ANNUAL MEETING OF THE CORDILLERAN SECTION OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT BERKELEY, CALIFORNIA, MARCH 31 AND APRIL 1, 1911 [1]

GEORGE D. LOUDERBACK, *Secretary*

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SESSION OF FRIDAY, MARCH 31

The twelfth annual meeting of the Cordilleran Section of the Geological Society of America was called to order in room 34, South Hall, University of California, Berkeley, at 2.15 p. m., March 31, 1911, by the chairman of the Section, Prof. A. C. Lawson.

The minutes of the previous annual meeting were read and approved.

[1] Manuscript received by the Secretary of the Geological Society of America February 19, 1912.

ELECTION OF OFFICERS

Ballot for officers for the ensuing year resulted as follows: A. C. Lawson, Chairman; George D. Louderback, Secretary; W. S. Tangier Smith, Councillor.

REPRESENTATION ON THE COUNCIL

The Secretary read a communication from the General Secretary concerning the proposed representation of the Cordilleran Section in the Council of the Society, in particular raising certain objections to the plan proposed by the Section, and asking for a more definite statement of the Section's attitude and wishes in the matter. After considerable discussion, the Section, by unanimous vote, instructed the Executive Committee to formulate the opinion of the Section and communicate the same to the Secretary and Council of the Society and to take all necessary action regarding the same.

At 3 p. m. the Section took up its scientific program and the following papers were presented in the order given:

NEOCOLEMANITE, A VARIETY OF COLEMANITE, AND HOWLITE FROM LANG, LOS ANGELES COUNTY, CALIFORNIA

BY ARTHUR S. EAKLE

A calcium borate occurs near Lang which differs somewhat from colemanite in its crystallographic and optic properties and the name neocolemanite is proposed to distinguish the variety. The deposit consists of alternate layers of crystallized borate and carbonaceous shales and has apparently been formed by the action of boracic acid on a lake or marsh deposit of calc-tufa or marl. The crystal forms and optical properties are described in detail. The silicoborate of lime, howlite, occurs with the neocolemanite as snow-white, nodular compact masses. It has been formed at the same time as the neocolemanite by precipitations from solutions containing soluble silica. The deposit is remarkable as a pure borate deposit unaccompanied by other calcium minerals or by sodium salts.

Manuscript prepared, but paper presented without reference to manuscript. This paper is published in the University of California, Publications of the Bulletin, Department of Geology, volume 6, June, 1911.

MINERAL ASSOCIATIONS AT TONOPAH, NEVADA

BY ARTHUR S. EAKLE

(*Abstract*)

The gold-silver deposits at Tonopah present a very instructive example of mineral associations and secondary formations of minerals in deposits situated in arid regions where chlorides and sulphides occur. Over forty mineral species occur, some of which are quite rare. The minerals are described in detail.

The meeting then adjourned to meet in conjunction with the Le Conte Club and Paleontological Society at the annual dinner Friday evening, and again met in regular session Saturday morning at 9 a. m.

At the dinner Friday night, held at the Faculty Club, Berkeley, Prof. H. F. Reid presented the following paper:

NOTE ON MOUNTAIN-PRODUCING FORCES

(Abstract)

The recent work of Doctor Hayford in proving the practical existence of isostasy shows that the elevation of mountains can not be ascribed to the accumulation of material by lateral pressure or by flow from below, but must be due to the expansion of the region under the growing mountains. These vertical forces are apt to cause normal faults near the boundaries of the rising area, and normal faults thus produced are very steep and in some cases are accompanied by tangential pressure.

This was followed by general discussion.

J. C. Merriam also presented the following:

SUGGESTIONS AS TO DEFINITIONS OF TERMS USED IN DESIGNATING UNITS OF GEOLOGICAL CLASSIFICATION

This also produced a general discussion.

Session of Saturday, April 1

The meeting was called to order at 9.45, in room 22, South Hall, and proceeded with the program.

In the absence of the writer, the following paper was read by title by the Chairman:

TERTIARY DEPOSITS OF OAHU

BY C. H. HITCHCOCK

(Abstract)

As a result of the study of more than four hundred artesian wells, it can be definitely stated that Tertiary deposits exist on Oahu between Koko Head and Barkers Point, and underlying several famous sugar plantations besides the city of Honolulu, and extending more or less entirely around the island, rising as much as 300 feet above the sealevel. The deposits consist of sand, conglomerates, clays, limestone, and sundry volcanic products resting on the hard basalt floor and perhaps a thousand feet thick and designated the Pearl Harbor series. Fossils indicate the Pliocene age. The later geological history of the island is outlined and an explanation given of the origin of the artesian waters.

The following papers were then presented:

FANGLOMERATE, A DETRITAL ROCK AT BATTLE MOUNTAIN, NEVADA

BY ANDREW C. LAWSON

(*Abstract*)

The paper is a brief description of an ancient alluvial fan formation observed at Battle Mountain. The alluvium has been thoroughly indurated by silicification in the same way that many sandstones are converted into quartzites, so that the rock is one of the most resistant to erosion in the region. Its constituent materials are angular fragments of various preexistent rocks, and its analogy with the modern incoherent waste of the desert alluvial fans is obvious. The rock is interesting not only as a petrographical type worthy of a name, but also, from a geological point of view, as a formation revealing a physiographic condition of the Great Basin province as a land surface in probably Mesozoic time.

Discussion by Hilgard, Louderback, and Rogers.

ORTHOCLASE AS A VEIN MINERAL

BY AUSTIN F. ROGERS

(*Abstract*)

Orthoclase as a vein mineral is described from two localities—Rawhide, Nevada, and Weehawken, New Jersey. At Rawhide there is a quartz-orthoclase vein, the orthoclase having the habit of adularia, the quartz having peculiar optical anomolies. At Weehawken narrow veins of orthoclase and calcite carrying pyrite and chalcopyrite occur in diabase. The orthoclase at this locality also has the habit of adularia.

Discussion by Lawson, Louderback, and W. S. T. Smith.

SOME GENERAL FEATURES OF THE MIOCENE OF THE SOUTHERN COAST RANGE REGION OF CALIFORNIA

BY GEORGE D. LOUDERBACK

(*Abstract*)

A general statement of the broader features and geological relations as observed, especially in Ventura, Santa Barbara, and San Luis Obispo counties, and discussion of the grouping and nomenclature of formations involved.

Discussion by Lawson, Anderson, Moron, and Merriam.

ORIGIN OF THE SANDSTONE AT THE STATE PRISON NEAR CARSON CITY, NEVADA

BY W. S. TANGIER SMITH

(*Abstract*)

From the size of this area, the character of the rock, its similarity to other sandstones in the adjoining region, the present and past existence of hot springs in the immediate vicinity, as well as other evidence, it is believed that this sandstone is the result of cementation of alluvial and æolian sands by hot springs deposits during late Pliocene or early Pleistocene time.

Discussion by Louderback, Merriam, and Anderson.

The meeting then adjourned for lunch, reassembled, and was called to order at 2 p. m.

The following papers were presented:

NOTES ON THE CENOZOIC HISTORY OF CENTRAL WYOMING

BY CHARLES LAURENCE BAKER

(*Abstract*)

The Cenozoic history of this portion of the central Rocky Mountain region can be best considered as beginning with the withdrawal of the last interior epicontinental sea at the close of the epoch of the Fox Hills sandstone in the northeast and east and of the Lewis shale in the southwest and south, provided that the view is taken that the major divisions of geologic time are separated by intervals of great diastrophism. In central Wyoming the Laramide period of deformation was accompanied by thrust faulting and volcanism. Intermontane structural basins formed by these complex orogenic movements were the sites of deposition of sediments eroded from the surrounding mountains during the Laramie epoch and earlier Tertiary times; later, when these basins had become filled, the places of maximum terrestrial deposition were shifted to the borders of the Cordilleran area. During the Green River epoch and probably during the Bridger also a lake, or lakes, existed in the Green River basins of southwestern Wyoming and northeastern Utah. A peneplain, which, according to all evidence at present available, probably existed over the entire region, was developed near the middle of the Miocene period. This first Cenozoic cycle of erosion was closed by an uplift, accompanied by volcanism, probably of later Miocene date, which appears to have been both regional and orogenic along the old lines of Cretaceous-Eocene movements. The Wyoming conglomerate and similar gravels covering flat-topped buttes and high inter-stream areas are believed to be the products of streams rejuvenated by the mid-Cenozoic uplift before the warped peneplain had been greatly eroded. The history of the yet existent second Cenozoic cycle of erosion has been great subaerial denudation of the loosely consolidated deposits of the basins and deep canyon-cutting in the more resistant rocks of the mountains. The drain-

age histories of the master streams are still very imperfectly known, but presumably a consequent superimposed origin of the Sweetwater River through the Wind River uplift and of the Green River through the Uinta Mountains accord better with the known facts than the older idea of their antecedent origin. Accidents, in the nature of at least two subcycles within the present cycle, have left their records in river terraces. There were at least two epochs of Pleistocene glaciation during which piedmont glaciers were formed on the peneplained flats of the mountains.

This paper was illustrated by maps and lantern slides.

NOMENCLATURE OF FAULTS

BY H. F. REID

(Abstract)

A committee has been appointed by the Geological Society of America to report on the nomenclature of faults. This is not the report, but the subject is presented here in order to obtain the views and criticisms of the members of the Cordilleran Section. No changes are introduced in the existing nomenclature, as far as that nomenclature is definite. Where several terms have been used for the same thing a single term is suggested, and where it has been thought advisable to introduce new terms these terms are as simple and as instructive as possible.

Discussion by Lawson and Wood.

CORRELATION OF THE TERTIARY DEPOSITS IN THE PACIFIC COAST AND BASIN REGIONS OF NORTH AMERICA

BY J. C. MERRIAM

GEOLOGY OF THE NEVADA HILLS

BY A. C. LAWSON

(Abstract)

An account of the geology and ore deposits at Nevada Hills, the principal points of interest being certain analogies with Tonopah on the one hand and with Ely on the other and evidence that the ores were not deposits by ascending solutions.

SECTION OF THE SHINARUMP

BY A. C. LAWSON

(Abstract)

The paper is a brief description of a stratigraphic section of the Shinarump, at Paria, southern Utah, and the relation of that series to the evolution of the Carboniferous platforms and Triassic cliffs of the Grand Canyon region.

NOTES ON THE PRE-GLACIAL GEOLOGY OF THE PUGET SOUND BASIN

BY CHARLES E. WEAVER

In the absence of the author the following papers were read by title:

GEOLOGICAL RECONNAISSANCE OF NORTHEASTERN NICARAGUA

BY OSCAR H. HERSHEY

SOME TERTIARY AND QUATERNARY GEOLOGY OF WESTERN MONTANA, NORTHERN IDAHO, AND EASTERN WASHINGTON

BY OSCAR H. HERSHEY

(*Abstract*)

Evidences of two stages of glaciation in Deer Creek Valley, Montana, are given and brief reference is made to the latest glaciation in the Cœur d'Alene Mountains of Idaho. A system of river terraces distributed for 30 miles along the valley of the South Fork of the Cœur d'Alene River is described in detail. The 1,150-foot terrace is probably early Miocene in age, but merely marks a vicissitude in the erosion of a valley 4,000 feet deep. In Middle Miocene time the Columbia River lava obstructed the valley and produced a lake in which were deposited white and variegated silts and the delta gravels of the river, filling the old valley 500 feet deep, to the level of the 600-foot terrace. A new valley 400 feet deep, partly on a new course, was trenched in early Quaternary time down to the 200-foot terrace. A remarkable distribution of granitic and gneissic boulders on this terrace is attributed to icebergs in a lake produced by the glacial damming of the valley at some point not determined; this is considered evidence of very early glaciation somewhere in northern Idaho. The 60-foot terrace is a gravel-capped rock bench, but the 30-foot terrace was built by the river and is tentatively correlated with the first glacial stage in Deer Creek Valley. Physiographic features of the Clearwater region and the lake plateau of eastern Washington are discussed, and Cœur d'Alene Lake and the Post and Spokane falls are explained as the result of the deposition of glacial overwash gravels in the broad Spokane Valley during the last glacial stage.

The meeting adjourned at 5.30 p. m.

During the session Mr. Wilkie, of Palo Alto, exhibited a collection of California tourmalines, benitoites, etcetera, in room 27, South Hall.

Register of the Berkeley Meeting

FELLOWS

F. M. Anderson
H. Foster Bain
A. J. Collier
A. S. Eakle
E. W. Hilgard
A. C. Lawson
G. D. Louderback
R. H. Loughridge
J. C. Merriam
H. F. Reid
W. S. Tangier Smith
J. A. Taff

Visitors and other geologists taking part in the meeting were C. L. Baker, G. C. Gester, R. S. Holway, Josiah Keep, R. W. Pack, F. Searls, C. E. Weaver, H. O. Wood, George J. Young. There were also present a number of students and other visitors. Altogether the attendance was as follows: Friday afternoon meeting, 31; Saturday morning, 35; Saturday afternoon, 37.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 23, PP. 77-92. MARCH 14, 1912

PROCEEDINGS OF THE THIRD ANNUAL MEETING OF THE PALEONTOLOGICAL SOCIETY, HELD AT WASHINGTON, D. C., DECEMBER 28, 29, AND 30, 1911

R. S. BASSLER, *Secretary*

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SESSION OF THURSDAY, DECEMBER 28, 1911

The opening session of the Society was called to order at 10 o'clock, Thursday morning, December 28, 1911, by Vice-President Arthur Hollick, in the new National Museum. Dr. Charles D. Walcott, Secretary of the Smithsonian Institution, welcomed the Society to Washington and made an informal address on the beginnings and progress of Paleontology in America.

The report of the Council, the first matter of business, was then presented.

REPORT OF THE COUNCIL

To the Paleontological Society in Third Annual Meeting assembled:

The regular annual meeting of the Council was held at Pittsburgh on the adjournment of the Society December 29, 1910. Since this meeting all business of the Society has been arranged by correspondence. The details of administration for the third year of the Society's existence are given in the following reports of officers:

Secretary's Report

To the Council of the Paleontological Society:

The proceedings of the second annual meeting of the Society, held at Pittsburgh, Pennsylvania, December 28-29, 1910, have been recorded in Volume XXII, pages 85-102, of the Bulletin of the Geological Society of America. Copies of this as well as of the other publications of the Society have been sent to every member.

At the annual meeting of the Council and by correspondence the list of officers for 1912 was prepared and, according to the By-Laws, forwarded to the members on March 19, 1911. It was then also announced that the third annual meeting of the Society would occur in Washington, D. C., beginning December 28, 1911, at the invitation of the Smithsonian Institution, extended through the Secretary, Dr. Charles D. Walcott.

During the past year the Society has lost one member by death, Prof. Samuel Calvin. Two resignations have become effective. The names of the eleven members elected at the Pittsburgh meeting have been added to the list and all of them have completed their membership according to rule. The present enrollment of the Society is 124. Twelve candidates are before the Society for election and thirteen applications are under consideration by the Council.

Following the authorization of the Council, Prof. J. C. Merriam organized a Pacific Coast section of the Paleontological Society, which held its first meeting last March. Professor Merriam reports a very successful meeting, with fourteen papers presented and about thirty in attendance.

At the last meeting of the Society a committee was appointed to prepare a report on securing a change in the classification of the freight rates on fossils. The chairman of this committee, Dr. W. J. Holland, has submitted the following:

Report of Committee Appointed at the Pittsburgh Meeting to Secure a Change of Classification in Freight Rates on Fossils

I desire to report that, as chairman of the committee appointed to secure a reduction in the rates which have hitherto been charged on fossils, immediately after the adjournment of the meeting I took the matter up with Mr. F. S. Holbrook, of the Official Classification Committee in New York, and with the officers of the Transcontinental Freight Association and the Southern Classification Committee. I was seconded in my efforts by Mr. Joseph Wood, the president of the Pennsylvania lines West, and other officers of the Pennsylvania Railroad, who extended to me every courtesy. As a result, the Official Classification in New York, which covers all of the roads east of the Mississippi River, acceded to my request, and by consulting their rate sheets the members of the Society will see that fossils extracted from rock, boxed,

are rated as first class; fossils in rock, less than carloads, are rated as second class, and in carloads of 30,000 pounds they are rated fourth class. The Western Classification Committee has supplemented its classification by the enactment of the following, to take effect after December 15, 1911:

Fossil specimens:	
In the rock:	
In crates	1
In barrels or boxes	2
In packages or loose, carload, minimum weight 24,000 pounds	4
Not in the rock:	
In barrels or boxes	1
In packages named, carload, minimum weight 20,000 pounds	3
Fossil casts or reproductions:	
Cement or plaster:	
In barrels or boxes	1
In packages named, straight or mixed, carload, minimum weight 20,000 pounds	3

Your committee apparently has not labored in vain. The rates accorded by the Western Classification Committee are slightly more favorable, as will be observed, than are accorded by the Official Classification in New York, representing the roads east of the Mississippi. Your committee would be happy, however, if all the railways could be led to feel, as he is aware some of the Western railroads do, that museums and colleges are properly regarded, and have been judicially held to be regarded as "charitable institutions," and that therefore the forwarding of scientific specimens *free of charge* might be undertaken without violation either of the spirit or letter of the regulations adopted by the Interstate Commerce Commission.

All of which is respectfully submitted.

(Signed) W. J. Holland,
Committee.

At the last election for Fellows in the Geological Society of America, E. B. Branson and Burnett Smith, members of the Paleontological Society, proposed by the Council, were elected to Fellowship. Walter Granger, Lawrence M. Lambe, E. S. Riggs, R. Anderson, Frank Springer, and C. R. Stauffer, of our Society, were also elected to Fellowship in the Geological Society of America on the nomination of individual Fellows of the two Societies.

The members of the Council representing Vertebrate Paleontology suggested a Symposium for the Washington meeting, entitled "Ten Years' Progress in Vertebrate Paleontology," and proposed a list of the

special subjects to be considered. The Council approved their suggestion and the program printed on a following page was arranged.

Respectfully submitted. R. S. BASSLER,
Secretary.

WASHINGTON, D. C., *December* 20, 1911.

TREASURER'S REPORT

To the Council of the Paleontological Society:

The Treasurer reports a prosperous year, dues both current and in arrears having been received from every member of the Society but five.

Such bills as were presented to the Treasurer were duly endorsed by the President and promptly paid. They were in excess of the annual expenditures, as up to the time of the present incumbent practically no bills had been presented against the Society, so that this year's outlay represents the entire expenses of the organization to date.

The Treasurer desires instructions on two points: whether or no he shall execute the bond of one thousand dollars ($1,000) as required by the Constitution, and as to the advisability of insuring the Society's funds against the possibility of loss other than by malfeasance in office.

The funds at present standing in the Treasury, deposited in the name of the Society in the Second National Bank of New Haven, Connecticut, are as follows:

RECEIPTS

Balance received from retiring Treasurer, Dr. W. D. Matthew		$141.91	
Dues of members (with arrears) for 1911 ($186.00 less $3.00 overcharge returned)		183.00	
			$324.91

EXPENDITURES

Treasurer's office:			
Postage	$3.00		
Stationery	11.84		
		$14.84	
Secretary's office:			
Expenses, 1910	16.80		
Secretary's allowance, 1910	50.00		
		66.80	
Geological Society of America, printing, stationery, postage, and clerical work ($43.95 less rebate of $2.25)		41.70	
Geological Society of America, Proceedings Paleontological Society, excess separates		18.50	
			$141.84
Balance on hand December 21, 1911			183.07
			$324.91

Respectfully submitted.

RICHARD S. LULL,
Treasurer.

NEW HAVEN, CONNECTICUT, *December*, 1911.

APPOINTMENT OF AUDITING COMMITTEE

The chair then appointed A. W. Grabau and T. W. Stanton as a committee to audit the Treasurer's accounts. In response to the Treasurer's inquiry regarding a bond of $1,000, a motion by John M. Clarke, duly seconded, was adopted by the Society to the effect that the funds in the Treasury were not sufficient at present to require such a bond of the Treasurer.

ELECTION OF OFFICERS AND MEMBERS

The declaration of the vote for officers for 1912 and for members was announced by the Secretary as follows:

OFFICERS FOR 1912

President:

David White, Washington, D. C.

First Vice-President:

J. C. Merriam, Berkeley, Cal.

Second Vice-President:

Rudolf Ruedemann, Albany, N. Y.

Third Vice-President:

E. W. Berry, Baltimore, Md.

Secretary:

R. S. Bassler, Washington, D. C.

Treasurer:

Richard S. Lull, New Haven, Conn.

Editor:

Charles R. Eastman, Pittsburgh, Pa.

MEMBERS

Harvey Bassler, Johns Hopkins University, Baltimore, Maryland.
Charles Butts, U. S. Geological Survey, Washington, D. C.
Will Edwin Crane, Swissvale P. O., Pittsburgh, Pennsylvania.
Julia Anna Gardner, Johns Hopkins University, Baltimore, Maryland.
F. C. Greene, Geological Survey of Missouri, Rolla, Missouri.
E. C. Jeffrey, Harvard University, Cambridge, Massachusetts.
Clara Gould Mark, Westerville, Ohio.
Maurice G. Mehl, University of Chicago, Chicago, Illinois.

RECTOR DUVAL MESLER, U. S. Geological Survey, Washington, D. C.
JAMES E. NARRAWAY, Department of Justice, Ottawa, Canada.
HERRICK EAST WILSON, University of Chicago, Chicago, Illinois.
WILLIAM JAMES WILSON, Geological Survey of Canada, Ottawa, Canada.

TITLES OF PAPERS ON GENERAL PALEONTOLOGY AND STRATIGRAPHY

After various announcements by the chair of arrangements for the meetings of the Society and other matters, the reading of the scientific papers, beginning with "General Paleontology and Stratigraphy," was taken up.

PHYSICAL CONDITIONS UNDER WHICH ORGANIC AND CHEMICALLY PRECIPITATED LIMESTONES ARE FORMED

BY T. WAYLAND VAUGHAN

Read by the author from manuscript; 15 minutes.

COASTAL PLAIN INVESTIGATIONS CONDUCTED BY THE UNITED STATES AND STATE GEOLOGICAL SURVEYS

BY T. WAYLAND VAUGHAN

Presented without manuscript; illustrated with lantern slides and maps; 20 minutes. This paper included a statement by L. W. Stephenson, read from manuscript by the writer.

STATE OF OUR KNOWLEDGE OF THE MIDDLE AMERICAN TERTIARY

BY WM. H. DALL

Presented from manuscript; 20 minutes.

REMARKS ON THE GEOLOGIC SECTION OF THE ISTHMUS OF PANAMA

BY D. F. MAC DONALD[1]

Presented without manuscript; illustrated with drawings; 20 minutes. Discussed by T. Wayland Vaughan and Ernst Howe.

At 12.30 p. m. the Society adjourned for luncheon, convening again at 2 p. m., with Vice-President Stuart Weller in the chair, when the papers on "General Paleontology and Stratigraphy" were continued, preceded by a memorial on Prof. Samuel Calvin.

MEMORIAL ADDRESS

Professor Weller spoke of the Society's loss by death during the year of Professor Calvin and reviewed his work in science, and especially his

[1] Introduced by T. Wayland Vaughan.

influence on his students. A memoir of Professor Calvin will be presented in the Bulletin of the Geological Society of America.

TITLES OF PAPERS AND NAMES OF DISPUTANTS

PALEONTOLOGY OF A VORACIOUS APPETITE

BY JOHN M. CLARKE

Presented by the author without manuscript; illustrated with lantern slides; 10 minutes. Discussed by A. W. Grabau and H. S. Williams.

CORRELATION OF THE PALEOZOIC FAUNAS OF THE EASTPORT QUADRANGLE, MAINE

BY HENRY SHALER WILLIAMS

Read from manuscript; 20 minutes. Discussed by H. M. Ami, J. M. Clarke, David White, and E. S. Bastin.

FOSSILIFEROUS CONGLOMERATES

BY A. W. GRABAU

Presented without manuscript; illustrated by sketches; 10 minutes. Discussed by R. Ruedemann, G. W. Stose, J. M. Clarke, C. A. Reeds, T. W. Stanton, W. T. Lee, Joseph Barrell, and Sidney Paige, with reply by the author.

ORISKANY SANDSTONES OF ONTARIO

BY CLINTON R. STAUFFER

Presented without manuscript; 10 minutes. Discussed by W. A. Parks and J. M. Clarke.

TO WHAT PART OF THE RICHMOND DOES THE MEDINA OF ONTARIO CORRESPOND?

BY A. F. FOERSTE

Presented without manuscript; 15 minutes. Discussed by A. W. Grabau, E. R. Cumings, E. O. Ulrich, and the author.

NOTES ON THE DICTYONEMAS OF NEW BRUNSWICK

BY F. F. HAHN[3]

Read from manuscript and illustrated with drawings; 10 minutes. Discussed by R. Ruedemann.

[3] Introduced by A. W. Grabau.

A NEW TRENTON CRINOID FROM ONTARIO

BY W. A. PARKS

Presented without manuscript; illustrated with lantern slides and specimen; 10 minutes. Discussed by A. W. Grabau.

At 5 o'clock the Society adjourned for the day.

Thursday evening the members of the Society took part in the Annual Dinner with the Fellows of the Geological Society of America.

Session of Friday, December 29.

Friday morning the Society was called to order at 10 o'clock by President Scott, who announced that the morning would be devoted to the papers on Invertebrate Paleontology, while the Symposium papers would be read during the afternoon session.

W. D. Matthew moved that the incoming Council be instructed to designate a bank of deposit for the Treasurer's funds; motion seconded and passed.

The Auditing Committee then reported that the accounts of the Treasurer were found to be in good shape.

TITLES OF PAPERS ON INVERTEBRATE PALEONTOLOGY

DEVELOPMENT OF THE MONTICULIPOROIDS

BY EDGAR R. CUMINGS

Presented without manuscript; illustrated with sketches; 20 minutes. Discussed by R. S. Bassler and J. M. Clarke.

MIDDLE CAMBRIAN CRUSTACEANS FROM BRITISH COLUMBIA

BY CHARLES D. WALCOTT

Presented without manuscript; illustrated with lantern slides and specimens; 20 minutes. Discussed by J. M. Clarke.

THE OZARKIAN FAUNA

BY E. O. ULRICH

Presented without manuscript; illustrated with lantern slides; 20 minutes. Discussed by C. D. Walcott, Charles Butts, A. W. Grabau, H. M. Ami, L. D. Burling, and E. O. Ulrich.

At 12.30 the Society adjourned for luncheon, convening at 2 p. m. for the reading of the Symposium papers.

SYMPOSIUM ON TEN YEARS' PROGRESS IN VERTEBRATE PALEONTOLOGY

The following papers, most of which are published as a brochure of volume 23, were then presented:

SOUTH AMERICAN MAMMALS

BY WM. B. SCOTT

Read from manuscript. Discussed by W. D. Matthew.

AFRICAN MAMMALS

BY W. D. MATTHEW

Read from manuscript. Discussed by H. F. Osborn and W. B. Scott.

PERISSODACTYLA

BY J. W. GIDLEY

Read from manuscript. Discussed by H. F. Osborn and W. D. Matthew.

CORRELATION AND PALEOGEOGRAPHY

BY H. F. OSBORN

Presented without manuscript. Discussed by W. D. Matthew and W. J. Sinclair.

CARNIVORA AND RODENTIA

BY W. D. MATTHEW

Read from manuscript.

MARINE MAMMALS

BY F. W. TRUE[3]

Read from manuscript. Discussed by W. B. Scott.

CRETACEOUS DINOSAURS

BY R. S. LULL

Read from manuscript by the author.

PRE-CRETACEOUS DINOSAURS

BY W. J. HOLLAND

Read in the absence of the author by R. S. Lull. Discussed by W. B. Scott.

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[3] Introduced by C. D. Walcott.

CONTRIBUTIONS TO GEOLOGIC THEORY AND METHOD

BY W. J. SINCLAIR

Read from manuscript. Discussed by W. D. Matthew.

ARTIODACTYLA

BY O. A. PETERSON

Read in the absence of the author by W. J. Sinclair. Discussed by W. D. Matthew.

PALEOZOIC FISHES

BY BASHFORD DEAN

Read by C. R. Eastman. Discussed by W. B. Scott and L. D. Burling.

MESOZOIC AND CENOZOIC FISHES

BY C. R. EASTMAN

Read from manuscript by the author. Discussed by W. B. Scott and L. D. Burling.

PRIMATES, MARSUPIALS, AND INSECTIVORES

BY W. K. GREGORY

Read in the absence of the author by W. D. Matthew. Discussed by W. B. Scott.

PALEOZOIC REPTILES AND AMPHIBIA, A COMPARISON OF OLD AND NEW WORLD FORMS

BY E. C. CASE

Read by member-elect M. G. Mehl.

MARINE REPTILES

BY J. C. MERRIAM

Read by W. J. Sinclair in the author's absence.

EVOLUTIONARY EVIDENCE

BY S. W. WILLISTON

Read by Stuart Weller.

At 5.30 the Society adjourned.

Friday evening the members of the Society attended the address of the retiring President of the Geological Society of America and took part in the smoker tendered to the Geological Society by the Geological Society of Washington at the Cosmos Club.

Session of Saturday, December 30

Saturday morning the Society was called to order at 10 o'clock by Vice-President Matthew.

TITLES OF PAPERS AND NAMES OF DISPUTANTS

NOTES ON DEVONIC CORALS

BY A. W. GRABAU

Presented without manuscript; illustrated with sketches. Discussed by R. S. Bassler, with reply by the author.

A FISH FAUNA FROM THE PENNSYLVANIAN OF WYOMING

BY E. B. BRANSON

Presented without manuscript; illustrated with lantern slides; 15 minutes. Discussed by R. S. Bassler, W. D. Matthew, A. L. Miller, and C. R. Eastman, with remarks by the author.

REMARKABLE SKELETON OF STEGOSAURUS

BY C. W. GILMORE

Read from manuscript; illustrated with lantern slides; 20 minutes. Discussed by R. S. Lull and W. D. Matthew.

REMARKABLE SPECIMEN BELONGING TO THE GENUS EDESTUS

BY O. P. HAY[4]

Presented without manuscript; illustrated with lantern slides; 15 minutes. Discussed by C. R. Eastman.

CRANIUM OF THE PLEURACANTHIDÆ

BY L. HUSSAKOF

Read by title.

JURASSIC SAURIAN REMAINS INGESTED WITHIN FISH

BY C. R. EASTMAN

Delivered without manuscript; illustrated with photographs; 5 minutes.

ESTABLISHMENT OF FAUNAL DIVISIONS AMONG THE VERTEBRATES OF THE PLEISTOCENE

BY O. P. HAY

Delivered without manuscript; illustrated with lantern slides; 30 minutes. Discussed by W. D. Matthew.

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[4] Introduced by R. S. Bassler.

Vice-President Eastman then took the chair and the following paper was presented:

NOTES AND SLIDES OF THE UINTA BASIN EOCENE

BY E. S. RIGGS

Given without manuscript; illustrated with lantern slides; 20 minutes.

TITLES OF PAPERS ON PALEOBOTANY

The two papers in Paleobotany listed below were then read by title on the request of their respective authors.

SOME INTERESTING NEW PLANTS FROM FLORISSANT, COLORADO

BY F. H. KNOWLTON

CHARACTERS OF CALAMITES INORNATUS DAWSON

BY DAVID WHITE

At 12.45 p. m. the Society adjourned.

Register of the Washington Meeting, 1911

MEMBERS

Henry M. Ami
Robert Anderson
Ralph Arnold
R. S. Bassler
J. W. Beede
E. W. Berry
A. B. Bibbins
E. B. Branson
L. D. Burling
John M. Clarke
William B. Clark
H. F. Cleland
E. R. Cumings
Wm. H. Dall
C. R. Eastman
August F. Foerste
J. W. Gidley
Theo. M. Gill
C. W. Gilmore
A. W. Grabau
Chris. A. Hartnagel
Arthur Hollick
Jesse E. Hyde
E. M. Kindle
Edwin Kirk
F. H. Knowlton
Richard S. Lull
Wendell C. Mansfield
W. D. Matthew
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RELATION OF GEOGRAPHY TO GEOLOGY [1]

ANNUAL ADDRESS OF THE PRESIDENT, W. M. DAVIS

(Read before the Society December 29, 1911)

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INTRODUCTION

Nearly a year ago I had occasion to speak at a meeting of the Geological Society of Washington on the subject "Geographical Descriptions in Geological Publications," with special reference to an explanatory

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method of describing the forms of the lands. In illustration of the principles that seemed to me most important I introduced a brief and technical geographical description of the land forms seen in the Front Range of the Rocky Mountains in central Colorado during an excursion in the summer of 1910, regarding which a fuller account is about to be published in the Annals of the Association of American Geographers; yet at the close of the meeting the feeling prevalent among some of the geologists present seemed to be that my description did not belong under geography, but under geology. The description had seemed to me to belong under geography, and to be indeed as good a piece of geography, in so far as land forms enter into geography, as I could make, because its object was the description of the existing landscape. Yet, in the opinion of geologically competent listeners, what I had said was not geography; it was geology. Evidently, then, the relations of these two sciences are not fully agreed on. I therefore propose to devote this address to the "Relation of Geography to Geology," with special relation to the forms of the lands, in the hope of showing at least my own grounds for regarding as geography what other members of our Society may consider to be essentially geology.

The address is divided into four parts. The first discusses the use of explanatory geological matter as a means to a geographical end; the second shows the necessity of explanatory treatment in modern geography; the third proposes a device by which the presence of geological matter in geographical descriptions is made inconspicuous, and the fourth turns more particularly to the general topic of the address, the relation of geography to geology.

Part I. The Use of explanatory geological Matter as a Means to a geographical End

AN EXPLANATORY DESCRIPTION OF THE COLORADO FRONT RANGE

The brief and technical description of the Front Range, the systematic place of which in the two sciences appeared last winter to be in doubt, was, as nearly as I can now reproduce it, as follows:

The Front Range of the Rocky Mountains in central Colorado, northwest of Denver, is a highland of disordered and generally resistant crystalline rocks, which show signs of having been long ago worn down from its initially greater mass to a surface of faint relief, slowly depressed and more or less broadly buried under a heavy cover of sedimentary strata. Then, as the result of a widespread uplift, a part of the compound mass west of a pronounced monoclinal displacement along a north-south line, came to stand above the rest, and thus the highland province of the moun-

tains was marked off from that of the less uplifted plains on the east. The forms of the highland shows that the whole region advanced far through the cycle of erosion introduced by the monoclinal uplift, so that the resistant underlying crystalline rocks of the mountain area were stripped of their cover and worn down to a gently rolling peneplain, diversified by irregularly scattered monadnocks, rising singly or in groups, with a relief of from 500 to 2,500 feet, while the valleys of the highland show that a renewed uplift gave the whole region a greater altitude than before, with a gentle up-arching along a north-south axis in the mountain area 15 or 20 miles west of the monocline, whereby the peneplain, with its scattered monadnocks, gained the highland altitude of the present Front Range; the crest of the up-arching and the monadnocks that happened to lie near it defining in a general way the crest of the range, which here constitutes the continental divide. The weaker strata of the plains are now again worn down to small relief, but the harder crystalline rocks of the mountainous highland are only submaturely dissected by normal submature or mature valleys, the higher parts of which have recently been strongly glaciated. Thus ends the description.

GEOLOGICAL ELEMENTS IN GEOGRAPHICAL DESCRIPTIONS

It is quite possible that many hearers now present will regard this description as having at least a highly geological flavor, even if they do not think it pure geology. Let us inquire, therefore, on what elements of the description such an opinion may be based. First, I presume, on the mention of certain kinds of rocks, namely, disordered crystallines and stratified sedimentaries; second, on the mention of the structure given to these rocks by uplift and deformation which took place in past ages; third, on the mention of erosional processes, glacial as well as normal, acting in the past, and of the work that they have accomplished. Let us examine these elements separately in the order just stated, with the object of learning how far their presence determines the geological or the geographical nature of a description that contains them.

If the mention of rock composition determines that a description should belong under geology instead of under geography, then such phrases as the cross-bedded sandstones of the White cliffs in southern Utah, the chalk cliffs of southeastern England, the basaltic columns of the Giants causeway, the dolomite mountains of the Tyrol, the sand dunes of the Sahara, and so on, all belong in geology and not in geography; nevertheless, such descriptions are often, and I think quite properly, found in geographical literature.

Rock attitude as well as rock composition may be mentioned, as in de-

scriptive phrases like the bench of horizontal sandstone overlying the disordered crystalline rocks which are exposed in the steep-walled gorge at the bottom of the Colorado Canyon, or the long ridges of steeply inclined sandstone strata, which turn in sharp zigzags around the gently pitching anticlines and synclines of the Alleghenies in central Pennsylvania. Such descriptions must be doubly geological if rock attitude as well as rock composition are allowed, mentioned only under geology and never under geography; but they surely deserve a place in geography also, for such descriptions are of great value in describing the visible features of existing landscapes.

If the mention of past processes of deposition, deformation, or erosion withdraws a statement from geography and transfers it to geology, then such phrases as wind-heaped sand dune, wave-built sand reef, wave-cut cliff, river-cut gorge, glacial cirque, tilted fault block, and uplifted peneplain are all geological. Indeed many simple terms, like delta, atoll, volcano, landslide, moraine, peneplain, in which it is tacitly implied that some process has acted through some portion of past time to produce a certain actually visible form, all become geological terms and must no longer be regarded as geographical. All these terms will be lost to geography if the explicit or implicit introduction of past process determines a term to be of geological nature; yet surely they belong in geography, and geography can not let them go. Doubly geological would be such phrases as a dissected volcanic cone; a maturely dissected landslide; an uplifted and slightly dissected delta; a tilted, dissected, and then glaciated peneplain; for these phrases suggest the action of past processes in double, triple, or quadruple succession, and thus imply the division of past time into chapters. Surely it is not to be questioned that such a treatment of existing forms has a highly geological flavor; yet the phrases, nevertheless, are to my reading good geographical phrases, because they so concisely and definitely characterize existing land forms.

If mention of process acting through time be associated with mention of rock composition and attitude, then descriptions thus phrased would be of a still more pronounced geological quality, provided that geological quality is really determined by mere mention of process, composition, and attitude; witness the following examples: A dissected bench of horizontal sandstones unconformably overlies the ancient peneplain of disordered fundamental crystallines in which the inner gorge of the Colorado Canyon has been eroded, or Snowden is a mass of deformed slates and lavas of subequal resistance, as a whole worn down to subdued form by normal erosive agencies, but possessing great cirques recently excavated in its valley heads by local glaciers. Yet both of these descriptions belong very prop-

erly, in my opinion, under geography, because they give us good pictures of land forms now existing.

Finally, if in addition to statements concerning the rock structure of the land-mass that is to be worked on, and concerning the erosive agents that do the work, we add some indication of the amount of erosional work that has been done by the working agent, and thus suggest a rather definite measure to the periods of past time that have been involved in the production of existing land forms, then the geological quality of such a description would become all the more pronounced, provided that mention of structure to be worked on, of agencies that have done the work, and of the stage of work reached by the agencies in their work on the structural mass necessarily determine a description to be geological instead of geographical. For example: Southern New England is chiefly composed of disordered and for the most part resistant crystalline rocks, with an irregularly defined north-south trend, which was long ago worn down to a peneplain, save for a few scattered monadnocks of small relief; since then uplifted to its present altitude with a gentle slant to the southeast, and after being for the most part maturely dissected by normal agencies, recently strongly glaciated by an overwhelming ice-sheet and then left in a slightly depressed position, so that the distal parts of its valleys are somewhat drowned. Or, again, central England is occupied by a heavy series of sedimentary strata, slanting gently to the southeast from an irregular and deeply eroded oldland of complicated structure, the sedimentary series including a first or basal member, a third or medial member, and a fifth or uppermost member of relatively weak clays or marly sandstones, and a second and a fourth member of relatively resistant limestone or chalk, the whole region seeming now to be in a well advanced stage of a second cycle of normal erosion, following the old age of a previous cycle, so that it possesses two well defined cuestas determined by the resistant strata, separating an inner, a medial, and an outer lowland eroded on the weak strata, all these features trending northeast-southwest with the strike of the strata and drained for the most part by well adjusted river systems.

CLASSIFICATION OF THE SCIENCES

Some students of earth science would regard brief descriptive phrases, such as a maturely dissected landslide or an uplifted and slightly dissected delta, as still in good measure geographical because of their simplicity, while they would regard the descriptions of New England and of old England, just quoted, and still more the longer description of the Colorado Front Range, as geological because of their greater quantity of

reference to rock structures and to past processes. But it may be fairly urged in relation to all these examples that the science to which a description belongs can not be determined by the devices that it employs, nor by the simplicity or the detail of the statements that it contains, but by the object in view and by the pertinence of such matters as are stated to the accomplishment of that object. Let me illustrate this principle by analogy.

When a chemist weighs a precipitate, does his work belong under physics because he for the moment gives up questions of composition and concerns himself with the action of forces? Does the work of a physiologist belong under chemistry because he for a time studies the composition of the digestive fluids of the human body? Does the work of a petrographer fall under chemistry when he uses chemical reagents in the analysis of his rocks, or under physics when he uses Nichols prisms and polarized light in the determination of his minerals? When a man calculates the orbit of a comet from three observations of its position in the heavens, is his work to be classed under mathematics or under astronomy?

The principle which must guide us in assigning a place to all such work is that it must be classed according to the object to which it is directed, not according to the means by which it is carried on, nor according to the detail with which it is elaborated. In the last case mentioned if the object sought is a fuller knowledge of a comet, the work belongs under astronomy, even though the means used in order to reach the object are mathematical. In all such questions it is the object and not the methods, the end and not the means, which determines the classification of the work done and of the man who does it. Utter confusion would result from any other plan of classification. Hence there is good and sufficient reason for saying that the description of the Front Range given below, and all the other descriptions and phrases that I have here introduced, are geographical descriptions and phrases, because their object has been the presentation of the facts regarding existing land forms, even if in gaining this object various facts regarding rock structures and past processes were freely employed whenever they were helpful. All of the descriptions here cited were carefully phrased in such a way as to lead up to existing facts. Emphasis was always intentionally placed on existing features and not on past conditions or processes, except in so far as these directly aid in appreciating present conditions. All geological matters which have no bearing on existing facts were excluded. No mention was made of geological periods in terms of their names, nor was any account given of the succession of events in past time, except in so far as such succession may throw light on the nature of the facts now visible.

GEOGRAPHICAL PERTINENCE OF EXPLANATORY PHRASES

Let me show explicitly how closely pertinent, how directly helpful every element of the description of the Front Range is in forming a just conception of the existing landscape. The range was described as "a highland of disordered and generally resistant crystalline rocks, which shows signs of having been long ago worn down from its initially greater mass to a surface of faint relief, slowly depressed and more or less broadly buried under a heavy cover of sedimentary strata." That condensed statement gives us a sufficient introductory understanding of the compound structural mass with which we have to deal. Next: "As the result of a general uplift a part of the compound mass west of a pronounced monoclinal displacement along a north-south line came to stand above the rest, and thus the province of the mountains on the west was marked off from that of the less uplifted plains on the east." This statement makes clear the attitude in which the compound mass was placed at the beginning of an important cycle of erosion, the work of which is at once intimated as follows: "The form of the highland shows that the whole region advanced far through the cycle of erosion introduced by the monoclinal uplift." From this the hearer may easily infer what is at once directly stated, namely, "that the resistant underlying crystalline rocks of the mountains area were stripped of their cover and worn down to a gently rolling peneplain, diversified with irregularly scattered monadnocks rising singly or in groups with a relief of from 500 to 2,500 feet." This is a most pertinent matter, for herein we find the explanatory conception of the broad surface of erosion, which is now seen in the highland of the Front Range. It might have been expected that scattered monadnocks would survive, even though much of the surface was peneplained, because the crystalline rocks were described as generally resistant, thus implying the occurrence of some variation in their resistance; and again that the surviving monadnocks would be irregularly scattered singly or in groups, because the structure of the crystallines was briefly described as "disordered." Had systematic trends characterized the arrangement of the rocks, and had pronounced difference of resistance characterized their composition, those structures would have been mentioned earlier; the absence of such mention indicates the absence of such structures and suggests the inference of scattered monadnocks. Although no explicit statement is made as to what happened during the same cycle of erosion in the plains area, it is easily inferred that the weak strata there exposed must have been worn down to extremely faint relief, because the resistant crystallines of the mountains area are explicitly stated to have been as a whole worn down to a gently rolling peneplain.

To continue: "The valleys of the highland show that a renewed uplift gave the whole region a greater altitude than before, with a gentle up-arching along a north-south axis in the mountain area 15 or 20 miles west of the monocline, whereby the peneplain with its monadnocks gained the highland altitude of the present Front Range, the crest of the up-arching and the monadnocks that happened to stand near the crest defining in a general way the crest of the range." All of this is immediately pertinent in presenting in an explanatory manner the form and attitude of the highland at the beginning of the present cycle, this initial form being the penultimate form of the preceding cycle, now uplifted to a new position. The description goes on further as follows: "The weaker strata of the plains are now again worn down to small relief," and from this we gain a general conception of the denuded plains truncating the monoclinal strata near the mountain border and stretching eastward indefinitely; but "the harder crystalline rocks of the mountainous highland are only submaturely dissected by normal submature or mature valleys"—that is, parts of the peneplain, surmounted by its monadnocks, must still be recognizable in rolling highlands between valleys, some of which, being described as submature, must be conceived as narrow and rock-walled, while others, described as mature, must be imagined as being more open, with waste-cloaked sides. The closing clause states that "the higher parts of the valleys have recently been strongly glaciated," and this at once suggests the excavation of cirques in the valley heads among the loftier monadnocks along the range crest and the transformation of the upper valleys into overdeepened and widened glacial troughs with oversteepened sides.

THE EXPANSION OF CONDENSED PHRASES INTO THEIR FULL MEANING

It must be apparent from the foregoing that the true geographical value of a condensed explanatory description can be reached only by expanding or translating each technical term or phrase into its full meaning with respect to the features of the existing landscape. The more successfully the translation is made the more fully will the reader's attention be brought forward from past conditions and processes to existing forms, and the more fully will the really geographical nature of this apparently geological description stand forth. An experienced reader can translate at sight; an inexperienced reader must give some time before he can explicitly state all the meaning that technical terms and phrases implicitly contain. In either case an attentive study will show that every element of the explanatory description of the Front Range bears immediately and helpfully on its present form, with the possible exception of a statement

made in the second or third line, namely, "a highland of disordered rocks, which shows signs of having been long ago worn down from its initially greater mass to a surface of faint relief, slowly depressed and broadly buried." Of what value, one may ask, is this reference to a long cycle of ancient erosion and planation before the depression and burial of the worn-down mass, and hence long before its monoclinal uplift and later erosion? In answer it may be said that the mention of ancient planation of the crystallines before the covering strata were laid down was intentionally introduced, because it is a factor of prime geographical significance in leading to an intelligent conception of one of the most characteristic features of the Front Range, namely, its abrupt and almost rectilinear border toward the plains, for if we imagine a compound mass, of which the under member was a worn-down body of disordered and resistant crystallines, while the upper member was a heavy series of sedimentary strata, and then conceive it to suffer monoclinal deformation, peneplanation, renewed uplift, and renewed erosion, by which the weaker strata east of the monocline are again peneplained, while the resistant rocks of the mountains are only submaturely dissected, the mountain area must then exhibit along its border a stripped part of the surface that was long ago worn down to faint relief, and hence the mountainous highland today must have an abrupt and rectilinear margin, in which the stripped part of the surface of ancient planation, tilted into a monoclinal slope, is exposed between the higher peneplain of the hard-rock highlands and the newer and lower peneplain of the weak-rock plains. The stripped planation surface of the mountain front will, of course, be cut down by numerous revived streams, where their valleys open from the highland; thus the continuous mountain border is transformed into a series of trapezoidal or triangular facets, of which the upper part will be somewhat the worse for wear, and the lower part may be still more or less covered by the basal members of the tilted plains strata; but for all that the mountain front, thus explained, must be conceived as abrupt and essentially rectilinear. The mountain front is indeed a great fragment of a fine geographical fossil, in the sense of being part of an ancient surface, either a land area or a sea floor, long preserved by depression and burial, and now, like many smaller fossil, brought to light by uplift and erosion, its higher extension completely destroyed and its exposed belt somewhat weather-beaten, while its lowest, deep-lying part still remains buried. It is a pleasure to put on record at this time and place that it was my friend and classmate, the lamented Archibald R. Marvine, who, as a member of Whitney's party in 1869 and of Hayden's Survey a few years later, first recognized the origin and the significance of this ancient surface of erosion.

IMPLICIT EXPLANATIONS IN GEOGRAPHICAL TERMS

In view of the foregoing, I am disposed to maintain the truly geographical nature of the description, beginning with: "The Front Range is a highland of disordered and generally resistant crystalline rocks," and ending with, "submaturely dissected by normal submature and mature valleys, the higher parts of which have recently been strongly glaciated." Its object is geographical throughout, in the sense that it strives to present a truthful picture of the existing mountains. It is geographical for just the same reason that a geographical quality is found in the phrases: "Here is a dissected volcano," "there is an uplifted and slightly dissected delta," "that is a peneplain, uplifted and gently tilted, maturely dissected and recently heavily glaciated." Indeed the description of the Front Range is geographical for the same reason that the still shorter phrases, "here is a delta," "there is a volcano," "that is a peneplain," are geographical. True, the description of the Front Range was much longer than the brief, four-word phrase last cited; true, the description of the Front Range made repeated and explicit mention of various rock structures and past processes, while rock structures and past processes are only implicitly suggested in such phrases as "this is a delta," "that is a volcano," "there is a peneplain." But the longer description and the shorter phrases are all geographical because their object is the description of existing features of the earth's surface. In this case and everywhere else it is the object in view and not any distinction between brevity and length, or between the implicit and explicit mention of rock structures and past processes, that should serve to determine whether a description belongs under geology or geography.

We may indeed fairly insist that if the description of the Front Range is not geographical, then the familiar geographical terms, delta, volcano, and peneplain, must also be withdrawn from geography, and that is manifestly absurd. There can surely be no question that these terms imply structure and process. When we say "delta" we do not mean merely low land near a river mouth; there is abundance of low land near river mouths along the Gulf coast of the Southern States that can not be included under this term. Whatever delta may have originally meant, it surely in this modern day means a deposit of river-brought land-waste, laid down with suggestive form and a highly significant stratified structure in relatively quiet water at a river mouth, where the efficiency of the river as a transporting agent is rather suddenly decreased; and, furthermore, a delta, thus understood, is perfectly well known not to be the product of a momentary action; its production has required a significant measure of

past time. Again, when we say "volcano" we mean the product of certain processes acting through a certain measure of time, as a result of which the thing produced has certain peculiarities of composition, structure, and form. Similarly, when we say "peneplain" we imply, in the mere mention of the term, the action of normal erosive processes on structures of any kind for a vast period of time, as well the land surface of small relief which the erosive processes have produced and which transects the underground structures indifferently. Structure and process are thus seen to be involved in the meaning of several familiar geographical terms in essentially the same manner that they are involved in more elaborate explanatory descriptions, such as that quoted for the Front Range. It would be absurd to regard the terms delta, volcano, and peneplain as geological instead of as geographical terms; hence it can not be reasonable to regard the description of the Front Range as geological instead of geographical.

TECHNICAL EXPLANATORY TREATMENT OF LAND FORMS

On the other hand, the description of the Front Range is not a good sample of elementary geography, nor of empirical geography, nor of full-fledged geography. The description was intentionally phrased to give an example of explanatory treatment as contracted with empirical treatment; of advanced grade and of technical style as contrasted with elementary grade and popular style; of condensed form instead of detailed form, and it was intentionally restricted to one subdivision of the inorganic or physiographic side of geography, namely, to that subdivision which is concerned with land forms; all other inorganic subdivisions, such as oceanic problems or climatic conditions, as well as all of the other side of geography, namely, its ontographic relations—the relations into which vegetable, animal, and human inhabitants enter with their inorganic environment—were intentionally omitted. The description being of advanced grade, it may well be impenetrable to juvenile geographers, but it is not thereby transferred to geology. Its advanced phrasing necessarily requires on the part of those for whom it was written a familiarity with various rocks, structures, and processes, so that a brief mention shall lead to an easy understanding of the landscape in which they result. Being of explanatory treatment, it may seem unfamiliar to empirical geographers, who vainly wish to limit their study to the earth's present surface, and who think that they have nothing to do with underground rock structure and past processes; but the description is not thereby lost to geography. Being condensed in form, its understanding may demand close attention if it is spoken or repeated reading if it is printed, for all

its implications have to be translated and expanded from conditions of rock structure and past processes into concepts of surface form, and this requires training. Being concerned only with land forms, the description is lacking in climatic elements and ontographic relations, and it is therefore incompletely geographical in the sense that the treatment of a section of a subject incompletely represents the whole subject; but it belongs none the less under geography, because it is explanatory, advanced, condensed, and incomplete. Hence I propose still to regard this explanatory, condensed description as a geographical description.

Part II. The Necessity of explanatory Treatment in modern Geography

EMPIRICAL AND EXPLANATORY GEOGRAPHICAL DESCRIPTIONS

In spite of all that has been said thus far, some of my more conservative hearers may regard all the explanatory descriptions thus far cited as belonging under geology, because, being explanatory, such descriptions necessarily have to do with the past, and in the mind of these hearers nothing that has to do with the past deserves to be classed under geography. There is, I fear, some reason for thinking that most of those who thus object to the explanatory method of geographical description and who reject such a description as that given above for the Front Range from geography were educated in the older-fashioned empirical school, and have never given much attention to the newer-fashioned and more rational method of geographical presentation. To them geography is only an empirical subject—that is, it deals only with immediately observable facts, independent of all theoretical explanations. Naturally, then, if they meet a geographical problem, treated in an explanatory manner, particularly if it includes an account of a group of land forms treated in terms of rock structure, erosional process, and stage of erosion reached, they do not recognize it as geographical and think it belongs to some other subject; but it is geographical all the same, because its object is the description of the visible landscape.

Empirical geographers may, however, object to this assertion, and ask why geography should be treated in an explanatory instead of in an empirical manner; why it should thus be made to trespass so far on geology as to include considerations of underground structures and past processes, instead of being content to describe visible forms directly in the good old-fashioned, superficial, empirical method, without making so much ado about it. A reason often given for the introduction of the modern and more penetrating rational method is that explanatory descrip-

erly, in my opinion, under geography, because they give us good pictures of land forms now existing.

Finally, if in addition to statements concerning the rock structure of the land-mass that is to be worked on, and concerning the erosive agents that do the work, we add some indication of the amount of erosional work that has been done by the working agent, and thus suggest a rather definite measure to the periods of past time that have been involved in the production of existing land forms, then the geological quality of such a desciiption would become all the more pronounced, provided that mention of structure to be worked on, of agencies that have done the work, and of the stage of work reached by the agencies in their work on the structural mass necessarily determine a description to be geological instead of geographical. For example: Southern New England is chiefly composed of disordered and for the most part resistant crystalline rocks, with an irregularly defined north-south trend, which was long ago worn down to a peneplain, save for a few scattered monadnocks of small relief; since then uplifted to its present altitude with a gentle slant to the southeast, and after being for the most part maturely dissected by normal agencies, recently strongly glaciated by an overwhelming ice-sheet and then left in a slightly depressed position, so that the distal parts of its valleys are somewhat drowned. Or, again, central England is occupied by a heavy series of sedimentary strata, slanting gently to the southeast from an irregular and deeply eroded oldland of complicated structure, the sedimentary series including a first or basal member, a third or medial member, and a fifth or uppermost member of relatively weak clays or marly sandstones, and a second and a fourth member of relatively resistant limestone or chalk, the whole region seeming now to be in a well advanced stage of a second cycle of normal erosion, following the old age of a previous cycle, so that it possesses two well defined cuestas determined by the resistant strata, separating an inner, a medial, and an outer lowland eroded on the weak strata, all these features trending northeast-southwest with the strike of the strata and drained for the most part by well adjusted river systems.

CLASSIFICATION OF THE SCIENCES

Some students of earth science would regard brief descriptive phrases, such as a maturely dissected landslide or an uplifted and slightly dissected delta, as still in good measure geographical because of their simplicity, while they would regard the descriptions of New England and of old England, just quoted, and still more the longer description of the Colorado Front Range, as geological because of their greater quantity of

reference to rock structures and to past processes. But it may be fairly urged in relation to all these examples that the science to which a description belongs can not be determined by the devices that it employs, nor by the simplicity or the detail of the statements that it contains, but by the object in view and by the pertinence of such matters as are stated to the accomplishment of that object. Let me illustrate this principle by analogy.

When a chemist weighs a precipitate, does his work belong under physics because he for the moment gives up questions of composition and concerns himself with the action of forces? Does the work of a physiologist belong under chemistry because he for a time studies the composition of the digestive fluids of the human body? Does the work of a petrographer fall under chemistry when he uses chemical reagents in the analysis of his rocks, or under physics when he uses Nichols prisms and polarized light in the determination of his minerals? When a man calculates the orbit of a comet from three observations of its position in the heavens, is his work to be classed under mathematics or under astronomy?

The principle which must guide us in assigning a place to all such work is that it must be classed according to the object to which it is directed, not according to the means by which it is carried on, nor according to the detail with which it is elaborated. In the last case mentioned if the object sought is a fuller knowledge of a comet, the work belongs under astronomy, even though the means used in order to reach the object are mathematical. In all such questions it is the object and not the methods, the end and not the means, which determines the classification of the work done and of the man who does it. Utter confusion would result from any other plan of classification. Hence there is good and sufficient reason for saying that the description of the Front Range given below, and all the other descriptions and phrases that I have here introduced, are geographical descriptions and phrases, because their object has been the presentation of the facts regarding existing land forms, even if in gaining this object various facts regarding rock structures and past processes were freely employed whenever they were helpful. All of the descriptions here cited were carefully phrased in such a way as to lead up to existing facts. Emphasis was always intentionally placed on existing features and not on past conditions or processes, except in so far as these directly aid in appreciating present conditions. All geological matters which have no bearing on existing facts were excluded. No mention was made of geological periods in terms of their names, nor was any account given of the succession of events in past time, except in so far as such succession may throw light on the nature of the facts now visible.

GEOGRAPHICAL PERTINENCE OF EXPLANATORY PHRASES

Let me show explicitly how closely pertinent, how directly helpful every element of the description of the Front Range is in forming a just conception of the existing landscape. The range was described as "a highland of disordered and generally resistant crystalline rocks, which shows signs of having been long ago worn down from its initially greater mass to a surface of faint relief, slowly depressed and more or less broadly buried under a heavy cover of sedimentary strata." That condensed statement gives us a sufficient introductory understanding of the compound structural mass with which we have to deal. Next: "As the result of a general uplift a part of the compound mass west of a pronounced monoclinal displacement along a north-south line came to stand above the rest, and thus the province of the mountains on the west was marked off from that of the less uplifted plains on the east." This statement makes clear the attitude in which the compound mass was placed at the beginning of an important cycle of erosion, the work of which is at once intimated as follows: "The form of the highland shows that the whole region advanced far through the cycle of erosion introduced by the monoclinal uplift." From this the hearer may easily infer what is at once directly stated, namely, "that the resistant underlying crystalline rocks of the mountains area were stripped of their cover and worn down to a gently rolling peneplain, diversified with irregularly scattered monadnocks rising singly or in groups with a relief of from 500 to 2,500 feet." This is a most pertinent matter, for herein we find the explanatory conception of the broad surface of erosion, which is now seen in the highland of the Front Range. It might have been expected that scattered monadnocks would survive, even though much of the surface was peneplained, because the crystalline rocks were described as generally resistant, thus implying the occurrence of some variation in their resistance; and again that the surviving monadnocks would be irregularly scattered singly or in groups, because the structure of the crystallines was briefly described as "disordered." Had systematic trends characterized the arrangement of the rocks, and had pronounced difference of resistance characterized their composition, those structures would have been mentioned earlier; the absence of such mention indicates the absence of such structures and suggests the inference of scattered monadnocks. Although no explicit statement is made as to what happened during the same cycle of erosion in the plains area, it is easily inferred that the weak strata there exposed must have been worn down to extremely faint relief, because the resistant crystallines of the mountains area are explicitly stated to have been as a whole worn down to a gently rolling peneplain.

To continue: "The valleys of the highland show that a renewed uplift gave the whole region a greater altitude than before, with a gentle up-arching along a north-south axis in the mountain area 15 or 20 miles west of the monocline, whereby the peneplain with its monadnocks gained the highland altitude of the present Front Range, the crest of the up-arching and the monadnocks that happened to stand near the crest defining in a general way the crest of the range." All of this is immediately pertinent in presenting in an explanatory manner the form and attitude of the highland at the beginning of the present cycle, this initial form being the penultimate form of the preceding cycle, now uplifted to a new position. The description goes on further as follows: "The weaker strata of the plains are now again worn down to small relief," and from this we gain a general conception of the denuded plains truncating the monoclinal strata near the mountain border and stretching eastward indefinitely; but "the harder crystalline rocks of the mountainous highland are only sub-maturely dissected by normal submature or mature valleys"—that is, parts of the peneplain, surmounted by its monadnocks, must still be recognizable in rolling highlands between valleys, some of which, being described as submature, must be conceived as narrow and rock-walled, while others, described as mature, must be imagined as being more open, with waste-cloaked sides. The closing clause states that "the higher parts of the valleys have recently been strongly glaciated," and this at once suggests the excavation of cirques in the valley heads among the loftier monadnocks along the range crest and the transformation of the upper valleys into overdeepened and widened glacial troughs with oversteepened sides.

THE EXPANSION OF CONDENSED PHRASES INTO THEIR FULL MEANING

It must be apparent from the foregoing that the true geographical value of a condensed explanatory description can be reached only by expanding or translating each technical term or phrase into its full meaning with respect to the features of the existing landscape. The more successfully the translation is made the more fully will the reader's attention be brought forward from past conditions and processes to existing forms, and the more fully will the really geographical nature of this apparently geological description stand forth. An experienced reader can translate at sight; an inexperienced reader must give some time before he can explicitly state all the meaning that technical terms and phrases implicitly contain. In either case an attentive study will show that every element of the explanatory description of the Front Range bears immediately and helpfully on its present form, with the possible exception of a statement

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IMPLICIT EXPLANATIONS IN GEOGRAPHICAL TERMS

In view of the foregoing, I am disposed to maintain the truly geographical nature of the description, beginning with: "The Front Range is a highland of disordered and generally resistant crystalline rocks," and ending with, "submaturely dissected by normal submature and mature valleys, the higher parts of which have recently been strongly glaciated." Its object is geographical throughout, in the sense that it strives to present a truthful picture of the existing mountains. It is geographical for just the same reason that a geographical quality is found in the phrases: "Here is a dissected volcano," "there is an uplifted and slightly dissected delta," "that is a peneplain, uplifted and gently tilted, maturely dissected and recently heavily glaciated." Indeed the description of the Front Range is geographical for the same reason that the still shorter phrases, "here is a delta," "there is a volcano," "that is a peneplain," are geographical. True, the description of the Front Range was much longer than the brief, four-word phrase last cited; true, the description of the Front Range made repeated and explicit mention of various rock structures and past processes, while rock structures and past processes are only implicitly suggested in such phrases as "this is a delta," "that is a volcano," "there is a peneplain." But the longer description and the shorter phrases are all geographical because their object is the description of existing features of the earth's surface. In this case and everywhere else it is the object in view and not any distinction between brevity and length, or between the implicit and explicit mention of rock structures and past processes, that should serve to determine whether a description belongs under geology or geography.

We may indeed fairly insist that if the description of the Front Range is not geographical, then the familiar geographical terms, delta, volcano, and peneplain, must also be withdrawn from geography, and that is manifestly absurd. There can surely be no question that these terms imply structure and process. When we say "delta" we do not mean merely low land near a river mouth; there is abundance of low land near river mouths along the Gulf coast of the Southern States that can not be included under this term. Whatever delta may have originally meant, it surely in this modern day means a deposit of river-brought land-waste, laid down with suggestive form and a highly significant stratified structure in relatively quiet water at a river mouth, where the efficiency of the river as a transporting agent is rather suddenly decreased; and, furthermore, a delta, thus understood, is perfectly well known not to be the product of a momentary action; its production has required a significant measure of

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TECHNICAL EXPLANATORY TREATMENT OF LAND FORMS

On the other hand, the description of the Front Range is not a good sample of elementary geography, nor of empirical geography, nor of full-fledged geography. The description was intentionally phrased to give an example of explanatory treatment as contracted with empirical treatment; of advanced grade and of technical style as contrasted with elementary grade and popular style; of condensed form instead of detailed form, and it was intentionally restricted to one subdivision of the inorganic or physiographic side of geography, namely, to that subdivision which is concerned with land forms; all other inorganic subdivisions, such as oceanic problems or climatic conditions, as well as all of the other side of geography, namely, its ontographic relations—the relations into which vegetable, animal, and human inhabitants enter with their inorganic environment—were intentionally omitted. The description being of advanced grade, it may well be impenetrable to juvenile geographers, but it is not thereby transferred to geology. Its advanced phrasing necessarily requires on the part of those for whom it was written a familiarity with various rocks, structures, and processes, so that a brief mention shall lead to an easy understanding of the landscape in which they result. Being of explanatory treatment, it may seem unfamiliar to empirical geographers, who vainly wish to limit their study to the earth's present surface, and who think that they have nothing to do with underground rock structure and past processes; but the description is not thereby lost to geography. Being condensed in form, its understanding may demand close attention if it is spoken or repeated reading if it is printed, for all

its implications have to be translated and expanded from conditions of rock structure and past processes into concepts of surface form, and this requires training. Being concerned only with land forms, the description is lacking in climatic elements and ontographic relations, and it is therefore incompletely geographical in the sense that the treatment of a section of a subject incompletely represents the whole subject; but it belongs none the less under geography, because it is explanatory, advanced, condensed, and incomplete. Hence I propose still to regard this explanatory, condensed description as a geographical description.

Part II. The Necessity of explanatory Treatment in modern Geography

EMPIRICAL AND EXPLANATORY GEOGRAPHICAL DESCRIPTIONS

In spite of all that has been said thus far, some of my more conservative hearers may regard all the explanatory descriptions thus far cited as belonging under geology, because, being explanatory, such descriptions necessarily have to do with the past, and in the mind of these hearers nothing that has to do with the past deserves to be classed under geography. There is, I fear, some reason for thinking that most of those who thus object to the explanatory method of geographical description and who reject such a description as that given above for the Front Range from geography were educated in the older-fashioned empirical school, and have never given much attention to the newer-fashioned and more rational method of geographical presentation. To them geography is only an empirical subject—that is, it deals only with immediately observable facts, independent of all theoretical explanations. Naturally, then, if they meet a geographical problem, treated in an explanatory manner, particularly if it includes an account of a group of land forms treated in terms of rock structure, erosional process, and stage of erosion reached, they do not recognize it as geographical and think it belongs to some other subject; but it is geographical all the same, because its object is the description of the visible landscape.

Empirical geographers may, however, object to this assertion, and ask why geography should be treated in an explanatory instead of in an empirical manner; why it should thus be made to trespass so far on geology as to include considerations of underground structures and past processes, instead of being content to describe visible forms directly in the good old-fashioned, superficial, empirical method, without making so much ado about it. A reason often given for the introduction of the modern and more penetrating rational method is that explanatory descrip-

tions are more interesting and more easily remembered than empirical descriptions. This is perfectly true, but it is not the whole or the chief truth. Let it here be understood that the duty of a geographer is two-sided; he must first gain a correct knowledge and he must then give an intelligible description of the facts of his subject; and it can not be doubted for a moment by any geographer who has carefully tried to fulfill both sides of his duty that both the investigation and the investigator are greatly aided by the adoption of an explanatory method. I believe this to be true in all branches of geography, and particularly in the study of land forms. Hence the strongest reason for advancing from the older-fashioned empirical treatment to the newer-fashioned explanatory treatment lies in the greater power of the newer treatment, in the power of deeper penetration on the part of the investigator into the real nature of the facts concerned, and, more particularly in relation to our present discussion, in the power of clearer and more intelligible presentation of the described landscape to the properly qualified reader. The ground for this statement, which is here still made with special reference to land forms, but which is I believe equally true for all divisions of geography, organic and inorganic, may be more fully appreciated by considering what follows.

ADVANTAGES OF EXPLANATORY TREATMENT

Whenever an explorer desires to describe the features of the landscape that he traverses, he must necessarily describe them in terms of previously acquired mental concepts, and these mental concepts may be called his mental geographical equipment; furthermore, after an explorer has written and printed a report on his explorations, his descriptions can be properly understood only by those readers who are in possession of essentially the same kind of mental geographical equipment as the one that the explorer possessed. Now, there are in use today two unlike kinds of mental geographical equipments for the descriptions of land forms—one made up of empirical concepts, independent of all theory, the other of explanatory concepts, which are absolutely dependent on theory. Empirical concepts must be learned by heart, for they are not reasonably connected by an understanding of the origin of the forms that they represent; they are simply matters of observational experience arbitrarily combined, too often after the fashion of these fanciful artistic compositions, picturing imaginary landscapes, which one used to see on an early page of geographical text books, and in which mountains and tablelands, waterfalls, and deltas were so marvelously juxtaposed. Explanatory concepts are, on the contrary, reasonably associated with one another and with the general principles from which they are derived, so that they are easily remembered in spite of their great variety.

Empirical concepts—I still speak especially regarding land forms—are known only as far as direct observation can penetrate, and they are therefore necessarily superficial in space, short-sighted in time, and rigid in definition. Explanatory concepts are known through and through, fore and aft: the farther side of the concept of a ridge is seen just as well as the near side, by the eye of the imagination, which takes any point of view that it desires; the inside of the ridge is seen as well as the outside, the past and the future forms of the ridge as well as the present form, for all these concepts are avowedly mental concepts only and not matters of fact. Explanatory concepts are, moreover, most elastic and adaptable, so that they may be easily made to match the facts of nature. Such concepts may be fanciful in the sense of not being necessarily counterparts of any natural forms; they may be erroneous in the sense of being incorrectly deduced from unsafe generalizations, and such chances of error must be recognized and guarded against. But the prime fact remains that explanatory concepts, deduced from general principles, are much more intimately and reasonably knowable than empirical concepts or even than facts of observation usually are, and in this quality of being intimately and reasonably knowable lies their highest value. It is as if one located them by sighting from many different points along the path of time, and thus fixed their position by the intersection of many converging lines of sight, while empirical concepts are located only by a single line of sight running in one direction from the viewpoint of the momentary present.

GROUNDS OF CHOICE BETWEEN EMPIRICAL AND EXPLANATORY METHODS

Let it, however, be clearly understood that the object of explanatory geographical descriptions is not the presentation of inferred facts concerning the past history of the earth, but the presentation of the most carefully defined concepts concerning the present earth. This is essential. The land forms of today may, of course, be used, just as stratified rocks or fossil prints are used, to constitute an observational basis for inferences regarding the past history of the earth, and the study of land forms with this object is a part of geology just as much so as the similar study of strata or of fossils, for it is, as already stated, the object of a study and not the thing studied or the method of studying it that determines the place of the study in a classification of the sciences. Inferences based on the form of the upland of southern New England as to the relatively modern date of its uplift from a long residence at a lower altitude belong under geology; but descriptions of the uplands of southern New England as the product of prolonged erosion during a lower stand of the land, fol-

lowed by uplift and by renewed erosion consequent thereon, belong under geography.

When it is perceived that there are two kinds of geographical equipment possible, and that both kinds are in use, it is evident that both must be learned by all who wish to understand current geographical literature. But when it comes to writing a description of an observed landscape the writer should, unless he is writing so carelessly that he combines the two equipments in a semi-conscious or accidental manner, consistently use either one equipment or the other. He has therefore to determine which one of the two equipments he will employ, and he will most wisely choose the one that gives the greatest aid in his practical work. Hence he ought to make conscious experiment with both methods, and his experiments ought, for the best results, to be made in duplicate—that is, several different landscapes ought to be treated in each of the two methods—and the resulting descriptions should be impartially compared. At the present stage in the evolution of geographical science nothing is more important in the education of a young geographer than intentional, impartial experiment with both these contrasted methods of description.

But it often happens that inborn temperament and habit of thought as determined by education are more influential than impartial judgment in making choice between the two methods. The empiricist objects to explanatory concepts because of their theoretical nature, their frequent complication, and their possible error; he prefers concepts of a simpler kind, based directly on observed forms and independent of all theory, because they are then—as he thinks—so easily conceived and so safe, or because they are so generally understood, and perhaps still more because they were taught to him years before. On the other hand, the rationalist finds empirical concepts insufficient in providing accurate and intelligible descriptions; he prefers explanatory concepts because, by the very reason of their complexity, they better represent the complexity of actual land forms and of increasing geographical knowledge. He frankly recognizes that explanatory concepts are relatively complicated, and he well knows that they must be made familiar by careful study before they can be easily and effectively used; he recognizes that if they are uncertain they must be used only in a tentative way until they are safely established; but he is willing to give time to establishing them and to familiarizing himself with them, because they prove to be so extremely helpful in his work.

The empiricist is apt to treat explanatory concepts as if they were mere fancies; he insists that he does not wish to go beyond matters of fact. The rationalist recognizes that while explanatory concepts are truly the

product of the imagination and not directly of observation, they can be rightly conceived only by use of a trained scientific imagination, for they are careful deductions from successful theories, the theories being based on abundant observation and induction, and the deductions being tested by repeated confrontation with facts. For this reason explanatory concepts represent the sum of pertinent knowledge thus far gathered, while empirical concepts represent only the beginning of the sum, for explanatory concepts contain all that is valuable in empirical concepts and a great deal more besides. Inborn temperament and habit of thought as determined by education may truly have much to do in determining which kind of equipment a geographer will use; but these vestiges of the past are not always our best guides when we have to make judgments regarding the future.

TREND OF MODERN GEOGRAPHY TOWARDS EXPLANATORY TREATMENT

The direction of modern progress in all branches of geography is distinctly toward the fuller development and the more general use of a mental equipment consisting of explanatory concepts. No one who compares geographical writings of fifty years ago and of the last ten or twenty years can fail to recognize this manifest tendency. If time permitted, an interesting story could be here introduced regarding the gradual progress from the old-fashioned empirical description of such features as shorelines toward their more thorough-going, more comprehensive, more advanced and mature, modern and explanatory treatment, or from the old-fashioned, blindly empirical description of our prairies to their newer-fashioned, illuminating, explanatory description, or from the meaningless, barren, empirical description of mountains in the older texts to their highly significant, fruitful, explanatory description in more modern books. No one who is aware of the change thus made and of the great progress that it marks is willing to return from the newer-fashioned to the older-fashioned method of treating land forms. Geography is today no longer the backward child that it was a century ago; it is growing up, even if it has not yet shown many signs of so rapid, indeed of so precocious a development as that of its younger sister, geology. The chief cause of the modern progress of geography is not the discovery of more mountains, more capes, more rivers, more islands; it is not the more elaborate enumeration of the kinds of plants and animals that inhabit a region, nor the fuller account of the location of cities and the boundaries of states, but the adoption, in the treatment of all geographical facts, of the evolutionary philosophy that has so profoundly modified all natural sciences; in a word, the adoption of explanatory theoretical concepts and terms for the description of observed facts.

It may be fairly asserted that practically every trained geographer, who has in recent years acquired a good understanding of both the empirical and the explanatory kinds of mental equipment and who has made a faithful comparison of their efficiency in the description of actual landscapes, has decided in favor of the explanatory equipment. Explanatory description is rapidly gaining acceptance wherever it is understood. Geographers of the older school still, naturally enough, prefer the empirical methods in which they were originally trained; yet even they use certain explanatory terms, such as sea-cliff, moraine, and many others, in a semi-conscious way; but they do not intentionally and whole-heartedly adopt the principle of explanatory description and carry it systematically forward to its full application. On the other hand, the most pronounced rationalist will not infrequently meet a feature of a landscape for which he can not provide a safe explanatory counterpart because he is not fully assured that he understands its origin. In such a case he may say, "It looks as if" it were so and so. In using such a qualifying phrase he frankly presents his best attempt at an explanatory description, and at the same time shows that he is in doubt about its correctness. He may indeed not infrequently encounter features for which he has no satisfactory explanation at all; he must then with equal frankness fall back on an empirical description, but always with expressed discontent; always with the hope and the effort to find the origin of the form and then to give it a properly explanatory description.

LIMITATION OF GEOLOGICAL ELEMENTS IN GEOGRAPHICAL DESCRIPTIONS

Let me in returning more particularly to land forms note again that what is here called the explanatory description of a landscape includes, as has been stated already, simply so many of the inferred facts of past time as bear helpfully on the understanding and description of the observed facts of present time. If this still savors of geology it may be urged that all ground for classing such a treatment under geology instead of under geography is withdrawn when the words "and no more" are added, thus: "The explanatory description of a landscape includes simply so many, and no more of the inferred facts of past time as bear helpfully on the understanding and description of the observed facts of the present time." There is, of course, no break in the backward stretch of the chain of causation from the geographical present into the geological past, but there is a limit soon reached as to the number of back-reaching links in the endless chain which are practically helpful in the description of existing forms—that is, helpful in forming mental counterparts of existing forms. German geographers are, in my judgment, inclined to introduce

too many links, and thus to encumber their geographical essays with so many inferred facts of remotely past occurrence, little related to present facts, that the reader's attention is distracted from instead of concentrated on the facts of present form.

Let me emphasize this principle by pointing out that the exclusion of irrelevant geological matter requires careful consideration. There is too frequently a tendency among geographers of the modern or evolutionary school to make mention of geological technicalities, which, however important they may be in geology, are unessential and irrelevant in geography. Many geographers would, for example, introduce into such a description as that given above for the Colorado Front Range petrographical and geological names for the deformed and generally resistant crystalline rocks of the highlands, and for the members of the heavy cover of sedimentaries now seen in the adjacent plains, and they would mention also the geological dates of the early planation, of the monoclinal deformation, of the later peneplanation, and of the final uplift of the district to its present altitude. All such matters are truly essential in a geological description, but they are unessential, irrelevant, distracting, and obstructive in a geographical description. If a better understanding of the appearance of the existing landscape can be gained by adding any one of these geological terms, then let it, of course, be added at once; but if not, let it be as carefully excluded.

It may well be that in his preparation for writing the description of a mountain range a geographer has occasion to examine many geological reports, in which he will repeatedly come upon such matters as names of formation, dates of unconformities and deformations, and so on. When he finally abstracts those parts of his accumulated information, which are to serve for a truly geographical description, all names of formation which imply geological dates and all names of fossils and of rare minerals will be carefully excluded. True, if a geographer wishes to make his geographical description serviceable to geologists, he may well enough include some mention of purely geological matters that are geographically irrelevant; but in the same way he might make his geographical essay useful to mathematicians by including some mention of the method of calculating logarithmic tables, or to classical philologists by adding some remarks on the increase of certain Latin nouns in the genitive. All such matters have their value somewhere and are all interesting to those who are interested in them; but none of them deserve a place in a geographical description unless they aid in the object of that description, namely, the portrayal of the existing landscape. If some of my hearers are skeptical on this point let them settle their doubts by making critical trials of pure

and of mixed geographical descriptions, and let them measure the strictly geographical value of their descriptions by giving a single-minded attention to their success in providing strictly geographical pictures. Naturally if a purely geographical description, from which geological terms are absent, is read by a geologist who wishes to know the names of rock formations he will find it unsatisfactory; but it is not for the purpose of giving satisfaction to a geologist that geographical descriptions are prepared. If, on the other hand, a geographer maintains that he as a geographer gains satisfaction from the mention of a geological formation by its technical date-name, let him try to specify exactly the way in which such mention gives him geographical satisfaction and he will find much difficulty in doing so. Let it, however, be clearly understood that if any writer, be he geographer or geologist, wishes to add to a geographical description supplementary information on any subject, such as the names of geological formations, a rule for the extraction of cube roots, or advice on the use of Latin subjunctives, he is, of course, perfectly free to do so; but do not let him think that in so doing he is making himself or his description more geographical.

The nature of a truly geographical description of explanatory style may be emphasized by pointing out the nature of a proper geological description. In a geological description each fact of existing structure serves, explicitly or implicitly, as a basis for inferences regarding past conditions and processes of deposition, deformation, intrusion, denudation, or other process, and each inference as to the conditions and processes of past time should be referred to its proper place in time-sequence in order to give due emphasis to the essentially historical aspect of geological science. Between this sort of a description and a properly geographical description there are abundant contrasts.

THE GEOLOGICAL NATURE OF CERTAIN GEOGRAPHICAL STUDIES

There are, however, articles of a certain kind, often written by geographers and published in geographical journals, and therefore commonly associated with geography, which more logically belong with geology. These are articles which are concerned with the past action of various processes in producing different kinds of land forms, and in which the manner of action of the processes and the nature of the forms that they produce is still under discussion, because the processes have not in this respect been fully investigated by those scientists who concern themselves chiefly with the operations of past time. A hundred years ago the disputed action of rivers in carving valleys occupied many pages of this kind; today the disputed action of glaciers in modifying land forms pro-

vides material for many similar pages. In writing such articles the geographer becomes for the time being and in a very limited way a geologist, for he is not trying to describe present forms, but to discover how certain agencies have acted in past time. As long as such problems are in discussion attention is naturally and properly more directed to past processes than to present results, and the investigation of past processes as such is evidently a geological matter. It is only after problematic processes are satisfactorily settled that they can be safely employed in explanatory descriptions of present forms; only then can the geographer return from his excursion on geological fields to his own science. Similarly a chemist, who wishes to filter or to weigh a precipitate and who finds no satisfactory methods of performing this purely physical process described in the standard works on physics, must for a while stop being a chemist and turn his attention to inventing a mechanical device for filtering or weighing things, thus transforming himself for the time being and to a limited extent into a physicist; but the invention once made and put to use as a means of finding out the composition of things, the investigator becomes a chemist again.

It is through considerations of this kind that one becomes convinced of the necessity of explanatory treatment in modern geography.

Part III. The Diminution of apparently geological Matter in geographical Descriptions

THE ADVANTAGE OF TERMS OVER PHRASES

In view of the demonstrations given in the foregoing pages, it should be understood that the place of a description in a classification of the sciences is determined by its object rather than by the means employed in reaching the object, and it should be recognized that explanatory geographical descriptions are of greater value than empirical descriptions; and from these conclusions it further ensues that the description of the Front Range given at the outset is not geology but good geography. If one grants the reasonable postulates with which the demonstrations begin and follows the demonstrations through their logical course, the conclusion just stated is inevitable; but do we not all know that many of us, especially our opponents, are not inclined to grant reasonable postulates, and that some opponents are unwilling to follow logical demonstrations? Do we not furthermore all know the opinion of the man who is convinced against his will? In view, then, of the difficulty of demonstrating to geologists the essentially geographical character of an apparently geological description, let us adopt another method of reaching a common

tions are more interesting and more easily remembered than empirical descriptions. This is perfectly true, but it is not the whole or the chief truth. Let it here be understood that the duty of a geographer is two-sided; he must first gain a correct knowledge and he must then give an intelligible description of the facts of his subject; and it can not be doubted for a moment by any geographer who has carefully tried to fulfill both sides of his duty that both the investigation and the investigator are greatly aided by the adoption of an explanatory method. I believe this to be true in all branches of geography, and particularly in the study of land forms. Hence the strongest reason for advancing from the older-fashioned empirical treatment to the newer-fashioned explanatory treatment lies in the greater power of the newer treatment, in the power of deeper penetration on the part of the investigator into the real nature of the facts concerned, and, more particularly in relation to our present discussion, in the power of clearer and more intelligible presentation of the described landscape to the properly qualified reader. The ground for this statement, which is here still made with special reference to land forms, but which is I believe equally true for all divisions of geography, organic and inorganic, may be more fully appreciated by considering what follows.

ADVANTAGES OF EXPLANATORY TREATMENT

Whenever an explorer desires to describe the features of the landscape that he traverses, he must necessarily describe them in terms of previously acquired mental concepts, and these mental concepts may be called his mental geographical equipment; furthermore, after an explorer has written and printed a report on his explorations, his descriptions can be properly understood only by those readers who are in possession of essentially the same kind of mental geographical equipment as the one that the explorer possessed. Now, there are in use today two unlike kinds of mental geographical equipments for the descriptions of land forms—one made up of empirical concepts, independent of all theory, the other of explanatory concepts, which are absolutely dependent on theory. Empirical concepts must be learned by heart, for they are not reasonably connected by an understanding of the origin of the forms that they represent; they are simply matters of observational experience arbitrarily combined, too often after the fashion of these fanciful artistic compositions, picturing imaginary landscapes, which one used to see on an early page of geographical text books, and in which mountains and tablelands, waterfalls, and deltas were so marvelously juxtaposed. Explanatory concepts are, on the contrary, reasonably associated with one another and with the general principles from which they are derived, so that they are easily remembered in spite of their great variety.

Empirical concepts—I still speak especially regarding land forms—are known only as far as direct observation can penetrate, and they are therefore necessarily superficial in space, short-sighted in time, and rigid in definition. Explanatory concepts are known through and through, fore and aft: the farther side of the concept of a ridge is seen just as well as the near side, by the eye of the imagination, which takes any point of view that it desires; the inside of the ridge is seen as well as the outside, the past and the future forms of the ridge as well as the present form, for all these concepts are avowedly mental concepts only and not matters of fact. Explanatory concepts are, moreover, most elastic and adaptable, so that they may be easily made to match the facts of nature. Such concepts may be fanciful in the sense of not being necessarily counterparts of any natural forms; they may be erroneous in the sense of being incorrectly deduced from unsafe generalizations, and such chances of error must be recognized and guarded against. But the prime fact remains that explanatory concepts, deduced from general principles, are much more intimately and reasonably knowable than empirical concepts or even than facts of observation usually are, and in this quality of being intimately and reasonably knowable lies their highest value. It is as if one located them by sighting from many different points along the path of time, and thus fixed their position by the intersection of many converging lines of sight, while empirical concepts are located only by a single line of sight running in one direction from the viewpoint of the momentary present.

GROUNDS OF CHOICE BETWEEN EMPIRICAL AND EXPLANATORY METHODS

Let it, however, be clearly understood that the object of explanatory geographical descriptions is not the presentation of inferred facts concerning the past history of the earth, but the presentation of the most carefully defined concepts concerning the present earth. This is essential. The land forms of today may, of course, be used, just as stratified rocks or fossil prints are used, to constitute an observational basis for inferences regarding the past history of the earth, and the study of land forms with this object is a part of geology just as much so as the similar study of strata or of fossils, for it is, as already stated, the object of a study and not the thing studied or the method of studying it that determines the place of the study in a classification of the sciences. Inferences based on the form of the upland of southern New England as to the relatively modern date of its uplift from a long residence at a lower altitude belong under geology; but descriptions of the uplands of southern New England as the product of prolonged erosion during a lower stand of the land, fol-

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But it often happens that inborn temperament and habit of thought as determined by education are more influential than impartial judgment in making choice between the two methods. The empiricist objects to explanatory concepts because of their theoretical nature, their frequent complication, and their possible error; he prefers concepts of a simpler kind, based directly on observed forms and independent of all theory, because they are then—as he thinks—so easily conceived and so safe, or because they are so generally understood, and perhaps still more because they were taught to him years before. On the other hand, the rationalist finds empirical concepts insufficient in providing accurate and intelligible descriptions; he prefers explanatory concepts because, by the very reason of their complexity, they better represent the complexity of actual land forms and of increasing geographical knowledge. He frankly recognizes that explanatory concepts are relatively complicated, and he well knows that they must be made familiar by careful study before they can be easily and effectively used; he recognizes that if they are uncertain they must be used only in a tentative way until they are safely established; but he is willing to give time to establishing them and to familiarizing himself with them, because they prove to be so extremely helpful in his work.

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LIMITATION OF GEOLOGICAL ELEMENTS IN GEOGRAPHICAL DESCRIPTIONS

Let me in returning more particularly to land forms note again that what is here called the explanatory description of a landscape includes, as has been stated already, simply so many of the inferred facts of past time as bear helpfully on the understanding and description of the observed facts of present time. If this still savors of geology it may be urged that all ground for classing such a treatment under geology instead of under geography is withdrawn when the words "and no more" are added, thus: "The explanatory description of a landscape includes simply so many, and no more of the inferred facts of past time as bear helpfully on the understanding and description of the observed facts of the present time." There is, of course, no break in the backward stretch of the chain of causation from the geographical present into the geological past, but there is a limit soon reached as to the number of back-reaching links in the endless chain which are practically helpful in the description of existing forms—that is, helpful in forming mental counterparts of existing forms. German geographers are, in my judgment, inclined to introduce

too many links, and thus to encumber their geographical essays with so many inferred facts of remotely past occurrence, little related to present facts, that the reader's attention is distracted from instead of concentrated on the facts of present form.

Let me emphasize this principle by pointing out that the exclusion of irrelevant geological matter requires careful consideration. There is too frequently a tendency among geographers of the modern or evolutionary school to make mention of geological technicalities, which, however important they may be in geology, are unessential and irrelevant in geography. Many geographers would, for example, introduce into such a description as that given above for the Colorado Front Range petrographical and geological names for the deformed and generally resistant crystalline rocks of the highlands, and for the members of the heavy cover of sedimentaries now seen in the adjacent plains, and they would mention also the geological dates of the early planation, of the monoclinal deformation, of the later peneplanation, and of the final uplift of the district to its present altitude. All such matters are truly essential in a geological description, but they are unessential, irrelevant, distracting, and obstructive in a geographical description. If a better understanding of the appearance of the existing landscape can be gained by adding any one of these geological terms, then let it, of course, be added at once; but if not, let it be as carefully excluded.

It may well be that in his preparation for writing the description of a mountain range a geographer has occasion to examine many geological reports, in which he will repeatedly come upon such matters as names of formation, dates of unconformities and deformations, and so on. When he finally abstracts those parts of his accumulated information, which are to serve for a truly geographical description, all names of formation which imply geological dates and all names of fossils and of rare minerals will be carefully excluded. True, if a geographer wishes to make his geographical description serviceable to geologists, he may well enough include some mention of purely geological matters that are geographically irrelevant; but in the same way he might make his geographical essay useful to mathematicians by including some mention of the method of calculating logarithmic tables, or to classical philologists by adding some remarks on the increase of certain Latin nouns in the genitive. All such matters have their value somewhere and are all interesting to those who are interested in them; but none of them deserve a place in a geographical description unless they aid in the object of that description, namely, the portrayal of the existing landscape. If some of my hearers are skeptical on this point let them settle their doubts by making critical trials of pure

and of mixed geographical descriptions, and let them measure the strictly geographical value of their descriptions by giving a single-minded attention to their success in providing strictly geographical pictures. Naturally if a purely geographical description, from which geological terms are absent, is read by a geologist who wishes to know the names of rock formations he will find it unsatisfactory; but it is not for the purpose of giving satisfaction to a geologist that geographical descriptions are prepared. If, on the other hand, a geographer maintains that he as a geographer gains satisfaction from the mention of a geological formation by its technical date-name, let him try to specify exactly the way in which such mention gives him geographical satisfaction and he will find much difficulty in doing so. Let it, however, be clearly understood that if any writer, be he geographer or geologist, wishes to add to a geographical description supplementary information on any subject, such as the names of geological formations, a rule for the extraction of cube roots, or advice on the use of Latin subjunctives, he is, of course, perfectly free to do so; but do not let him think that in so doing he is making himself or his description more geographical.

The nature of a truly geographical description of explanatory style may be emphasized by pointing out the nature of a proper geological description. In a geological description each fact of existing structure serves, explicitly or implicitly, as a basis for inferences regarding past conditions and processes of deposition, deformation, intrusion, denudation, or other process, and each inference as to the conditions and processes of past time should be referred to its proper place in time-sequence in order to give due emphasis to the essentially historical aspect of geological science. Between this sort of a description and a properly geographical description there are abundant contrasts.

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There are, however, articles of a certain kind, often written by geographers and published in geographical journals, and therefore commonly associated with geography, which more logically belong with geology. These are articles which are concerned with the past action of various processes in producing different kinds of land forms, and in which the manner of action of the processes and the nature of the forms that they produce is still under discussion, because the processes have not in this respect been fully investigated by those scientists who concern themselves chiefly with the operations of past time. A hundred years ago the disputed action of rivers in carving valleys occupied many pages of this kind; today the disputed action of glaciers in modifying land forms pro-

vides material for many similar pages. In writing such articles the geographer becomes for the time being and in a very limited way a geologist, for he is not trying to describe present forms, but to discover how certain agencies have acted in past time. As long as such problems are in discussion attention is naturally and properly more directed to past processes than to present results, and the investigation of past processes as such is evidently a geological matter. It is only after problematic processes are satisfactorily settled that they can be safely employed in explanatory descriptions of present forms; only then can the geographer return from his excursion on geological fields to his own science. Similarly a chemist, who wishes to filter or to weigh a precipitate and who finds no satisfactory methods of performing this purely physical process described in the standard works on physics, must for a while stop being a chemist and turn his attention to inventing a mechanical device for filtering or weighing things, thus transforming himself for the time being and to a limited extent into a physicist; but the invention once made and put to use as a means of finding out the composition of things, the investigator becomes a chemist again.

It is through considerations of this kind that one becomes convinced of the necessity of explanatory treatment in modern geography.

Part III. The Diminution of apparently geological Matter in geographical Descriptions

THE ADVANTAGE OF TERMS OVER PHRASES

In view of the demonstrations given in the foregoing pages, it should be understood that the place of a description in a classification of the sciences is determined by its object rather than by the means employed in reaching the object, and it should be recognized that explanatory geographical descriptions are of greater value than empirical descriptions; and from these conclusions it further ensues that the description of the Front Range given at the outset is not geology but good geography. If one grants the reasonable postulates with which the demonstrations begin and follows the demonstrations through their logical course, the conclusion just stated is inevitable; but do we not all know that many of us, especially our opponents, are not inclined to grant reasonable postulates, and that some opponents are unwilling to follow logical demonstrations? Do we not furthermore all know the opinion of the man who is convinced against his will? In view, then, of the difficulty of demonstrating to geologists the essentially geographical character of an apparently geological description, let us adopt another method of reaching a common

understanding regarding the ground to be cultivated and the means to be employed in geography, the older but less developed sister science of geology.

It has already been shown that various terms, such as delta and volcano, which undoubtedly belong under geography, are really only concise names for things that result from a more or less complicated series of processes acting through a longer or shorter period of time, so that if the terms were expanded into their full meaning the resulting phrases would be classified under geology by those of us who would place in that science the explanatory account of the Front Range with which this address began. Let me illustrate this point more fully.

If instead of saying "volcano" one should expand this simple word into its whole meaning, there would be much to be told about the long continued action of a whole series of past processes; there would first be an explicit statement about the prevolcanic foundation; then something about the initial stages of eruption, with their associated explosions, earthquakes, growing cinder cones, outspreading lava flows, and far-carried ash showers; there would be mention of intermediate periods of erosion, with the outwash and deposition of torrent-borne volcanic agglomerates on the neighboring lower lands; of renewed volcanic activity, in which dikes split their way upward, or in which the earlier volcanic summit is engulfed only to be built up again higher than before, with renewed explosive outbursts, with lava flows and ash showers that fill the valleys eroded in the earlier cone, and so on over and over again, for a volcano is a complicated affair. Surely no self-respecting volcano that has gone through all these violent throes of growth and all these periods of apparent exhaustion would be content to be thought of as a ready-made article without a past. Indeed if a geographer says "volcano" without more or less distinctly conceiving all this complicated series of past processes he confesses himself deficient in scientific inauguration. Furthermore, no volcano that has properly played its destructive part in organic evolution would be satisfied with an account which made no mention of the way eruptions had repeatedly overwhelmed the organic inhabitants of its district, burning and burying successive populations that had mistaken the foundation or the flanks of the cone for a safe habitation. Indeed, when we properly link volcanic growth with organic evolution, we may come to discover that the existing population of a large volcanic district recently and repeatedly overwhelmed by lavas and ashes, as in central Mexico, is chiefly made up of such plants and animals as could repeatedly return after repeated destructions and expulsions, and hence that in such a population we should find for the most part active settlers, while slow

colonizers would have been killed or driven out and never had a chance to return. True, when a beginner in geography first meets the word volcano and learns likely enough that it is a burning mountain he gains no very full understanding of all these dramatic changes, just as when he first studies history he gains no real appreciation of all the long continued oppressions and struggles that eventually culminate in the outburst of a revolution, of which he learns hardly more than the date. But does volcano truly mean anything less than all the complication of events that is here briefly sketched? Must not a mature and thoughtful geographer strive when he says "volcano" to visualize the long succession of active eruptions and quiescent periods, of upbuildings and downwearings, of organic destructions and recolonizations which the single word, volcano, implies; must he not conceive all this long succession through which alone he can come to know what the existing volcano really is? And just in the same way must not the mature historian go far beyond the schoolboy in conjuring up slow-moving pictures of the past when he speaks of a revolution, if he wishes to know what the revolution really was?

It is the same with the brief phrase, "a mature river." There was a time not very long ago when a river with a maturely graded course could be regarded, even by mature geographers, as simply an existing thing without their feeling any concern about the long series of changes which must inevitably have run their course before maturity could be reached; but that time is not ours. No modern geographer who recognizes the evolution of the present from the past—and no modern geographer can fail to do that—no modern geographer can escape from imagining the young stages of a river as preceding the mature in order properly to appreciate the mature stages. Still more, if one speaks in concise terms of "a meandering valley maturely incised in an uplifted peneplain of disordered structure," must the appreciative understanding of this descriptive phrase build up the conception of the present on a long succession of past events, and indeed not only on a succession of inorganic events, but of organic events as well; for, as Woodworth first pointed out and as Cowles has later so fully shown, there is a most intimate, systematic, and essential correlation between these inorganic changes and the organic changes that lead up to the present organic population of an uplifted peneplain of disordered structure, traversed by an incised meandering valley, and no proper account of the present populations can be given without an appreciation of their past. Yet surely a geographer who understands the abundant implications of the term volcano may use it without being considered as encroaching on geological grounds, and he may even speak of an uplifted peneplain traversed by an incised mean-

dering valley without exciting remark as being an overventurous trespasser, although it is plain that the real meaning of the single term volcano, as well as of the explanatory descriptive phrase, is crammed full of past conditions and processes and changes. But if he explicitly paraphrases those past changes, as was done in case of the long explanatory account of the Front Range, he is regarded as having left his proper field for that of geology.

The lesson from this is clear enough. If, instead of describing the structures and reciting the succession of events that lead up to the existing forms which are treated in the explanatory description of the Front Range, we had a single term which immediately indicated the general result of all this succession, the term might be used with all its implications and yet without exciting the fear that in using it geographers were metamorphosing themselves into geologists. True, if the Front Range were the only example of its kind, it would be hardly worth while to invent a term to name it; but such is by no means the case. Similar successions of events on similar structures producing similar forms are well known elsewhere, and a generic term for all of them, with specific adjectives to indicate their different expressions, would be very helpful in geographical descriptions. Let it be remembered that in inventing and using a single term for the easy statement of a complicated idea or type, geographers would only be following the example set by workers in other sciences. Consider the biological term metabolism; instead of attempting here to define its meaning, we may accept the assurance of biologists that this word is packed full of elaborate meaning, and that its use saves much round-about paraphrasing. Geographers might well follow the example of their fellow-scientists in this respect. Allow me to recount a recent experiment in the invention of a systematic name for such district as that of the Colorado Front Range.

AN EXPERIMENT IN THE INVENTION OF A TERM

During a geographical pilgrimage from Ireland to Italy that I conducted in the summer of 1911, several of the pilgrims tried to find a term that might be used to name a region of composite structure, consisting of an older undermass, usually made up of deformed crystalline rocks, that had been long ago worn down to small relief and that was then depressed, submerged, and buried beneath a heavy overmass of stratified deposits, the composite mass then being uplifted and tilted, the tilted mass being truncated across its double structure by renewed erosion, and in this worn-down condition rather evenly uplifted into a new cycle of destructive evolution. The older mass of such a structure would in its relation to the

younger part possess the essential features of the Front Range in central Colorado, of central Wisconsin, of eastern Devonshire, of eastern Brittany, of the western and northern border, of the central highland of France, of the northeastern extension of this highland, known as the Morvan, of the western side of the Vosges, of the eastern side of the Odenwald and the Schwarzwald. In northern Arizona there is an ideally perfect example of such a structure, which instead of being uplifted in modern geological times into a new cycle of erosion, was in ancient geological times depressed and buried under about two miles of strata, the triple mass being afterward uplifted and so deeply eroded that the buried double mass is shown in a superb natural section at the bottom of the Grand Canyon of the Colorado. It would be helpful to have a name that should be used in talking about the recurrent geographical features of all such structurally similar masses, the name being applied more particularly to the area of the older resistant rocks which ordinarily stand in relief as an upland or highland in the current cycle, but at the same time being used to indicate the relation in which the upland or highland stands to the adjacent lower area of inclined stratified rocks. Structurally considered, the problem here involved has been called by one of my students the problem of intersecting peneplains; but that is a phrase, not a name; so the search for a name had to be continued during our summer pilgrimage and for some time without success, until one day, patience being exhausted, I exclaimed: "Let us call the thing a skiou!" "What is a skiou?" asked my companions. "A skiou is the thing we have been talking about." "What is the origin of the word?" "It hasn't any origin; it is made up from nothing, like the words "gas" and "boss;" let us use it till we find something better." "How is it spelled?" "It never has been spelled, but it is going to be spelled s-k-i-o-u; its plural shall be in s, and its gender is masculine." This last declaration, be it noted, was made to satisfy my French and German companions. Thereupon skiou was used by all of us in a provisional way, and one of the party illustrated a number of different kinds of skious by a series of block diagrams, in which the essential elements were given different values. When a new pilgrim joined us, we talked familiarly of skious in his presence, just as petrographers talk of eleolite-syenites, or hypersthene-andesites, wherever they are; thereupon the newcomer would lean toward his neighbor and ask in an undertone, "What is a skiou?" and his neighbor would say aloud, "Don't you know what a skiou is! Say, fellows, here is a man who never heard of a skiou." Thus we developed a sort of initiation ceremony, and when the next newcomer arrived it was for his predecessor to exclaim, "What! have you never heard of a skiou?"

But the serious side of our fun was that the term served its purpose; it saved time in our discussions and saved space in our note books; but it may now be supplanted by a more satisfactory term, to wit, morvan, the name of the northeastern extension of the central highland of France, which is, as already mentioned, an excellent example of the skiou kind. True, the French Morvan, from which the covering strata dip very gently to the north, is limited on the east and west by faults, and hence its extension along the strike of the covering strata is of moderate measure; but this will be regarded as an individual feature; other morvans may have a greater extension and may be terminated in other ways. Like meander and monadnock, morvan may be written with a small m, to indicate its generic value, and it may be pronounced by us in plain English fashion, like Paris and France.

MORVANS OF DIFFERENT KINDS

A few days' exercise on morvans will suffice to form acquaintance with many imaginary examples, each one possibly the counterpart of an actual region. Such exercise enriches the mental equipment of a geographer by providing him with various sorts of morvans; one, for instance, may be imagined in which the undermass consists of deformed and resistant crystalline rocks; the first planation was perfectly accomplished, the covering strata possessed abundant thickness and variable resistance, the lowest member being weak; then the uplift tilted the double mass to the north at a small angle; the second planation was less complete than the first, the broad uplift which introduced the present cycle was of moderate measure, and the stage of erosion now reached is early mature in the resistant undermass, and late mature in the covering strata to the north, on which a series of alternating cuestas and lowlands are now developed along the strike of the stronger and weaker members. Now, if the covering strata are imagined as faulted down on the east and west at the time of the gentle northward tilting, such a morvan would fairly represent the original morvan itself.

Another example might retain a considerable relief when depression and burial occurred, and might be given a moderately strong tilting to the east, north, and south when uplift took place; it might then be for the most part well worn down, yet retain a number of smaller and larger monadnocks on its hardest rocks; it might next be broadly uplifted and, in the cycle thus introduced, the resistant undermass of disordered crystallines might be maturely dissected while the weak lower members of the covering strata were reduced to a new lowland, and this example would then represent the uplands of Devonshire near their eastern border. If to

such a series of events we add a recent and slight depression, whereby the bordering lowland is drowned on the north and south and the sea is thus allowed to attack the border of the maturely dissected hard-rock uplands along the base of their stripped slope, we should have the best brief explanatory account that I have been able to gather of the north and south coasts of that picturesque region.

During the deduction of a series of imaginary morvans, or during the observation of a number of actual cases, a geographer has occasion to make repeated mention of the essential elements which recur with different values in every example, and he will thus in the most natural manner possible come to designate the elements by the same set of names and to qualify each of them by selected sets of adjectives. He will talk of the undermass or the oldermass, and of the covering strata or overmass or cover, and he will note that in most cases the undermass is composed of disordered resistant crystalline rocks, while the stratified series in the cover are usually less resistant; he will talk of the earlier peneplain, now partly revealed in a stripped belt, where the inclined cover has been worn off of the undermass; of the later peneplain, now more or less dissected in the upland or highland to which the term morvan more particularly applies, and more or less completely destroyed in the area of the cover, which may indeed be worn down to a third peneplain, and of the morvan angle, namely, the acute angle between the intersecting peneplains. The more definitely these elements are conceived and the more concisely and consistently they are named, the easier will it be to describe new examples, imaginary or real.

THE COLORADO FRONT RANGE IS A MORVAN

Conceive a morvan in which the undermass was worn down to a remarkably smooth peneplain in its first cycle of erosion, heavily covered with for the most part weak strata, uptilted to the east at a strong angle, then long eroded, so that even the hard rocks of the undermass were reduced to a gently rolling later peneplain, here and there interrupted by good sized monadnocks, irregularly placed, singly or in groups; we should thus have the morvan, which, when again uplifted and this time with broad up-arching to a lofty altitude, and when then submaturely dissected in its harder western undermass, of which the higher parts are well carved by local glaciers, while the weaker eastern covering strata are worn down a thousand feet lower to a new peneplain, would represent the Colorado Front Range and the adjacent plains here under discussion. In other words, the Colorado Front Range is a morvan, in which a belt of the earlier peneplain appears as an inclined surface slanting about 30

degrees to the east—notched by many revived consequent valleys—along the eastern mountain border, in which the later peneplain is seen in the lofty, gently inclined and maturely dissected highland of the mountainous area, interrupted here and there by strong monadnocks, rising singly or in groups, with strongly glaciated forms in the higher valley heads, and in which the covering strata are as a whole so weak that they are now worn down to a third peneplain of faint relief far and wide to the east of the mountain base, except that a resistant member near the base of the covering strata stands up, parallel to the mountain base, as a subsequent ridge inclosing a piedmont subsequent valley.

It would be interesting again to meet some of the geologists who claimed for geology the account of the Front Range, as given a year ago and here reproduced at the opening of this address, and to ask them whether they would claim for geology also the account of the range just now given as a morvan. The two accounts are unlike in certain respects: the second one is shorter than the first, because the mere introduction of the significant term morvan implies the occurrence of a number of features that had to be explicitly explained in the first account, and the first account contains several verbs in the past tense, while all the verbs in the second account are in the present tense. But in spite of these differences of length and tense, the two accounts are essentially alike, and to my understanding of the case, if the second account belongs to geography, then both the accounts belong there.

CONCEALED GEOLOGICAL MEANING IN VARIOUS GEOGRAPHICAL TERMS

The most important difference between the two accounts is evidently the lack of the explanatory term morvan in the first and its introduction in the second. The meaning of the term must of course be studied beforehand by any one who wishes easily to understand the second account, and such study manifestly involves a certain familiarity with geology; but this does not warrant the transfer of the account from geography to another science. Likewise the meaning of such a term as eleolite-syenite must of course be studied beforehand by any one who hopes to understand a description in which that term is found, and such study manifestly involves a certain knowledge of chemistry and physics; but this does not require the exclusion of such a description from geology.

It is the same with delta, volcano, mature river, and dissected peneplain. Descriptions in which these terms occur can not be understood without previous study of their meaning, and their meaning inevitably involves a consideration of past conditions and processes; nevertheless the terms stand and deserve to remain within the domain of geography.

The properly explanatory definition of these terms enforces this conclusion. A delta, for example, is not properly defined simply as having a flat lowland surface at a river mouth, nor yet as having been formed by the deposition of river-brought waste at the river mouth, but as having a flat lowland surface, because of having been formed by the deposition of river-brought waste at the river mouth. Similarly a dissected peneplain ought not to be defined as an upland district of subequal altitude, transecting rock structures indifferently and here and there interrupted by valleys, nor yet as a district which once stood lower and was then worn down to low relief by normal erosional processes, and which was afterward uplifted and in this new altitude partly cut down by its revived rivers; but as an upland district, in which the accordant hilltop surface transects the rock structures indifferently because of having been worn down to low relief by normal erosional processes during a former lower stand of the region, and which is now here and there interrupted by valleys because of the revival of erosive processes in virtue of later uplift. Neither the empirical statement of present fact nor the geological account of origin suffices in such definition. A double definition is necessary in which geological origin is closely associated with present form, for thereby the essentially geographical nature of these terms is made clear.

The same is true of the term morvan. A morvan is not best defined simply as a hard-rock upland, whose resistant mass descends rather smoothly under a neighboring lower district occupied by stratified rocks, nor yet as a region that has been through such and such changes during its long past history, but as a region that exhibits a hard-rock upland or highland bordered by a lower land of slanting stratified rocks because of having suffered such and such changes in its long past history; and thus defined, morvan may be added to the growing list of well established geographical terms.

Part IV. The Relation of Geography to Geology

GEOGRAPHY IS THE GEOLOGY OF TODAY

The description of the Colorado Front Range as a morvan will, I trust, be regarded as properly geographical by nearly all members of this Society; but it may still be that some of the more serious objectors may refuse to be blinded by the use of a mere term, and may declare that no such subterfuge can conceal from them the essentially geological quality of any explanatory description that is essentially based on the

past history of a region. To these members, who very likely think that the word geography has already entered more often than is proper in an address before a geological society, I am prepared to offer still another statement, which it is to be hoped they will find conciliatory, for if they still urge that the account of the Front Range as a morvan belongs under geology I wish now to reply: Of course it does, for all geography belongs under geology, since geography is neither more nor less than the geology of today, and since all geology is essentially the sum of a long succession of past geographies. The separation of the geographical part from the geological whole was a natural consequence of the opinions that prevailed a century ago, when most geographers were merely observational empiricists and most geologists were in large measure fanciful catastrophists; but such a separation is, systematically considered, an absurdity at the beginning of the twentieth century, when we are all convinced that the flow of the past into the present has been without a break, and when we all believe that the geological past, with its days and nights, zones and seasons, calms and storms, lands and waters, rivers and waves, and its striving inhabitants, vegetable and animal, is best pictured in the geographical present, for whatever differences may be found the resemblances are overwhelmingly greater. As the past is indeed nothing but an endless succession of geographies, the present member of the succession naturally claims great attention from geologists as well as from geographers, because it is the visible standard for all the rest; all the earlier members can be known only as departures from it. It is therefore utterly illogical, in so far as the nature of their content is concerned, to classify the past and the present conditions of the earth under two sciences. Consider how closely alike would be the subjects of two investigations, one directed to an account of the earth at the beginning of Carboniferous time, the other to an account of the earth as it is today! Each investigation would treat of a momentary phase in a long evolution; each would introduce as much of the preceding phases as might aid the appreciative understanding of the phase under discussion. To be sure, the study of Carboniferous geography would probably include a considerable discussion of petrographic problems, which would be ordinarily treated lightly in accounts of today's geography, while today's geography would have much to do with local details of mean annual temperatures and rainfalls, which unfortunately can not be minutely treated under Carboniferous geography; hence there would be characteristic differences between the two investigations. Nevertheless the two would have as many elements in common as any two morvans would have, although the elements would of course have different

values for Carboniferous time and for today, just as the elements of two morvans, one in France, the other in Colorado, have different values. No; the difference between these two investigations would not lie so much in the unlikeness of their content as in the inherently speculative character and the inevitable incompleteness of one and the largely observational character and the eventually attainable completeness of the other. The speculative character of all conclusions regarding the earth's past history is indeed, when once recognized, so striking that it becomes a matter of surprise to see that geology is largely taught as an observational science, and that direct instruction in the best methods of speculation is ordinarily neglected.

REASONS FOR MAINTAINING EACH AS A SEPARATE SCIENCE

If, then, the content of geology, the long past of the earth, and of geography, the momentary present, are so much alike, why should we make two sciences of them and organize two societies for their cultivation? Chiefly for practical reasons. The degree to which specialization is carried in these modern times demands the division of various subjects that really have a logical unity of content. And among the most important of these practical reasons is that the separation of one group from the whole body of considerations to which the group belongs promotes the concentration of interest and attention on that group, and thus aids its progress. It is only some twenty years ago that geologists and biologists were united in the Society of American Naturalists, and the meetings of that society were so interesting that when it was proposed to segregate the geologists in a society of their own I was one of those who doubted the wisdom of such a step. But the organization of the Geological Society of America has been so beneficial to our science that, far from opposing further subdivision, I took an active part in promoting it when eight years ago a few of us, mostly members of this society, formed the Association of American Geographers; and here again the results gained from independent organization have fully justified the partial isolation that our separation entailed. Our relations are still close, so close indeed that besides a good number of interchangeable members and a somewhat too large number of interchangeable papers, we have in two cases had interchangeable presidents, and as the second one of these I hold it to be a great honor to find myself to that extent in the same category with the first one.

Nevertheless, the most characteristic papers in the two societies are significantly unlike, and with further development of geographical science I am persuaded that their unlikeness will in certain respects increase, for geographers are going to give more and more attention to the accurate portrayal of existing landscapes—the term landscape being here used in so general a sense that it includes the seas and the skies and their inhabitants along with the lands—while geologists will, I believe, give increasing attention to the restoration of ancient landscapes. But the unlikeness will never overcome the likenesses that must maintain the two societies in close relations. Should one of the geographers some day wander, as it is to be hoped he may, into a meeting of the geologists, let us trust that he would have occasion to remark: "That is an excellent account of, for example, the central Appalachian region in Oriskany time, for in spite of being completely speculative, as all restorations of the invisible past must be, it is so ingeniously and logically constructed out of the small existing body of accessible facts, all of which have been patiently searched out and scrupulously used, and it is so successful in vividly portraying the probable conditions and correlations of things, inorganic and organic, throughout central Appalachia in that remote period of earth history which geologists call Oriskany!"

Should, on the other hand, one of the geologists some day visit a meeting of the geographers, where he would surely be welcome, let us hope that he would have good reason for exclaiming: "That is an excellent description of, for example, Patagonia, for while always holding faithfully to the rich store of observable facts, which are sometimes so numerous as to embarrass a geographer from their very abundance, the paper is so significantly suggestive of the evolutionary meaning of the facts, inorganic and organic, and while not for a moment losing sight of the observable present, it so helpfully describes existing conditions in terms of pertinent and illuminating speculations as to their invisible origin, thus showing that the accessible present is really comprehensible only when it is regarded as a continuation of the inaccessible past!"

It is considerations of this nature that make me confident of the abundant work of both these societies and of their sufficient individuality in spite of their close relation; the older one, geology, already well established, penetrating by brilliant speculation the deep structures of the earth's crust and the past conditions, inorganic and organic, of the earth's history, but necessarily basing all its speculations on the facts and conditions of the present surface, which belong so largely in the field of the newer one; the newer one, geography, growing in efficiency year by year,

contributing to the wide exploration that in time will cover all the facts and conditions, inorganic and organic, of the earth's present surface, and coming more and more to base its best descriptions on the explanatory speculations regarding structures beneath the earth's surface and regarding the processes and conditions of the earth's past history, that have been so ingeniously invented and so wonderfully well established by studies in the field of the older one.

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PLEISTOCENE OF SIOUX FALLS, SOUTH DAKOTA, AND VICINITY[1]

BY B. SHIMEK

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[1] Manuscript received by the Secretary of the Society February 23, 1911.

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Introduction

The region which surrounds Sioux Falls, South Dakota, particularly that part lying south and east on both sides of the Big Sioux River and extending south to Fairview, South Dakota, has received much attention from students of Pleistocene geology. This is due to the fact that it displays two drifts and was supposed to lie partly in the sinus of a marginal lobe of the Wisconsin drift border, including ridges which were thought to be portions of the Altamont moraine. It also contains fossiliferous interglacial silt and gravel beds which have attracted attention.

Work and Conclusions of previous Observers

The region was first carefully studied by Todd, whose preliminary report on the geology of South Dakota[2] contains a description of four moraines, of which the first or outer moraine[3] is described (page 116) as extending "to a high point south of Canton. It is then feebly developed, or entirely absent, from that point to the west side of the Big Sioux opposite the northwest corner of Iowa. There it forms a ridge running west, south of the great bend of the Big Sioux near Sioux Falls." In the same paper (page 110) he provisionally refers certain "beds of clay and sand . . . which are clearly preglacial," along the valley of the Big Sioux

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[2] J. E. Todd: South Dakota Geological Survey, Bulletin No. 1, 1895.

[3] This had been named the *Altamont Moraine* by Dr. T. C. Chamberlin in the preliminary paper on the terminal moraine of the second Glacial epoch. Third Annual Report of the U. S. Geological Survey, 1883, p. 388. The map, plate xxxv, represents this moraine as passing east and west into the great bend of the Big Sioux River east of Sioux Falls, and thence south along the Big Sioux River for more than 50 miles. Dr. Chamberlin's later map, published in Geikie's "The Great Ice Age," 3d edition, 1895, gives the Wisconsin border somewhat the same location, but represents the Kansan as occupying a strip along the west side of the Big Sioux near and south of Sioux Falls,

outside of the outer moraine, to the Equus beds, which he places in the Pliocene. He also describes (page 111) a Pleistocene section near Fairview, gives a good description of what is evidently Kansan drift (page 113), and reports the finding of remains of *Elephas* and mastodon near Sioux Falls.

In 1898 Bain, who had worked in the field with Todd, reported[4] a great "Wisconsin gravel train, occupying the valley of the Big Sioux," and in the same paper (page 350) he argues that the predominating drift of northwestern Iowa "clearly is not Kansan," but adds that "there are traces of Kansan drift at several points in the region discussed. At Sioux City there are certain old gravels which can hardly be referred to anything younger. Near Sioux Falls similar old material has been noted."

In 1899 Todd published[5] a revised view of the drift of the region, recognizing two drifts between which lie gravels, and also a dark soil containing shells of modern mollusks, a vertebra of a horse and remains of a turtle.

The most complete report on the geology of the region was presented by Todd in 1899.[6] The map, plate I, shows morainic ridges east of Sioux Falls, and morainic knobs northeast of Canton, but does not represent any part of the moraine as extending into the northwestern part of Lyon County, Iowa. Speaking of the first (outer) or Altamont moraine he says (page 19): "About 5 miles east-southeast of Sioux Falls it reappears on the west bank of the Big Sioux, and curves around the bend of the Big Sioux at Sioux Falls." He describes four knobs northeast of Canton as forming a part of the same moraine (page 34). He also discusses the terraces along the Big Sioux River (pages 138-140), and concludes that they belong to the earlier Glacial Epoch. The report also contains a record of the Pleistocene section west (erroneously printed east) of Fairview (page 83), of a section northeast of Sioux Falls (page 84), and another east of Canton on the Big Sioux (page 86). The sands and clays under the drift are again referred to the Pliocene (page 67). It is evident that he considered the upper till Wisconsin, and specifically (page 128) referred to the "Altamont moraine of the Wisconsin Epoch."

Wilder was the next to take up the discussion of this region in his report on the geology of Lyon and Sioux counties, Iowa.[7]

These counties border the Sioux River on the Iowa side, and their western portions are included in our territory. Wilder attempted to connect

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[4] Iowa Geological Survey, vol. viii, p. 339.

[5] New light on the drift in South Dakota. Proceedings of the Iowa Academy of Sciences, vol. vi, pp. 122-130.

[6] Bulletin No. 158 of the U. S. Geological Survey.

[7] Frank A. Wilder: Iowa Geological Survey, vol. x, 1900.

his work with that of Todd. He considered the flat plain on the west side of the Big Sioux a Wisconsin drift-plain and contrasted it with the Lyon County surface, which is higher and "older and its drainage more perfectly developed" (page 94). He also recognized "a finely developed Wisconsin gravel train" following the Big Sioux (pages 130, 138), and Wisconsin gravel terraces along other streams (pages 141-143). Not only did he recognize the Altamont moraine substantially as traced by Todd on the South Dakota side, but he extended it into the western part of Lyon County, Iowa, and represented it definitely on the map of that county (pages 137-143). He states that "from the point where the moraine crosses the river west of Granite to Sioux Falls it is easily traced as a well defined boulder-strewn ridge. It passes east of Sioux Falls and crosses the river 2 miles northeast of the town." In the last particular he disagrees with Todd, who located the moraine south of Sioux Falls.

Wilder considered the drift of Lyon and Sioux counties Kansan, but concluded with Salisbury, Bain, Leverett, and Todd (page 128) that the lower drift in the Illinois Central Railway cut east of Sioux Falls, and in similar cuts in Sioux Falls, is Kansan, the upper drift in his opinion being Wisconsin.

He also observed sand, gravel, and clay beneath the drift, of which he says (page 97) that they are not readily classified, but probably should be referred to the Pliocene. He found that these sands are not local; that at Akron[8] and Sioux City they contain mammalian fossils, and that they are younger than the Cretaceous and older than the drift. On the basis of the decision that the lower drift at Sioux Falls is Kansan, he refers these sands and gravels to the Buchanan.

The next extended contribution was that of T. S. Bendrat,[9] who agreed on the whole with Todd. In plate II he figures the Altamont moraine south of Canton and again south of Sioux Falls, and connects these elevations by the chain of knobs already mentioned (page 85). He represents the moraine as loess-covered. He states that sometimes sand and gravel separate two blue tills, and sometimes a blue and a yellow till, and evidently considered them a part of the drift.

In 1908 Todd again discussed a portion of our territory in the Elkpoint folio,[10] and expressed doubt that the prevailing drift is Kansan, but suggested that it may be Iowan (page 3). The sketch-map, figure 3,

[8] The elephant bones reported from Akron are probably those which the writer recently secured for the Iowa Geological Survey. They are bones and teeth of *Mammut merificum* and are Aftonian.

[9] The geology of Lincoln County, South Dakota, and adjacent portions. American Geologist, vol. xxxiii, 1904.

[10] Geological Atlas of the United States, Elkpoint folio. U. S. Geological Survey,

page 3, represents the Altamont moraine as crossing the Big Sioux River into Lyon County, Iowa. He also refers to pre-Wisconsin gravels (page 3), and presents again the Otis Mill section opposite Chatsworth.

Finally, L. H. Harvey,[11] incidentally discussing the geology of southeastern South Dakota and northwestern Iowa in connection with the plant ecology of the region, and probably not writing from personal knowledge, refers to the Altamont moraine between the Big Sioux and the Missouri rivers and mentions the obliteration of the "questionable pre-Kansan."

The foregoing references indicate clearly that the ridges and knobs in the region immediately east and southeast of Sioux Falls have been regarded as a part of the early Wisconsin Altamont moraine; that this moraine was extended into Iowa; that the flat plains along the west side of the Big Sioux River between Canton and Sioux Falls were considered a part of the Wisconsin plain; that the great gravel beds along the Big Sioux were regarded as Wisconsin gravel trains; that two drifts were recognized near Sioux Falls, of which the upper was Wisconsin and the lower probably Kansan, and that the gravel, sand, and silt beds between these two drifts were viewed as equivalent to the Buchanan.

Recent developments resulting from the study of the Pleistocene deposits in western Iowa raised a doubt as to some of the foregoing conclusions, and an investigation was undertaken by the writer in connection with the work of the Iowa Geological Survey.

Field Work

The writer visited repeatedly the region in question during the past 15 years, and, not venturing to dissent from the opinion of expert geologists, concluded several years ago that if the ridges near Sioux Falls and opposite Granite are parts of the Altamont moraine, then the latter must extend on the Iowa side along the Big Sioux River at least to the uplands opposite Canton, for these ridges are topographically and structurally the same.

The investigation of the Aftonian deposits, which is being carried on by the writer for the Iowa Geological Survey, made it necessary to see this region again, and about a month (with several subsequent visits, each covering from two to five days) was spent in the field during the summer of 1910 along the Big Sioux River between Sioux Falls and Canton, and later the work was continued down the Big Sioux to connect with the

[11] Floral succession in the prairie-grass formation of southeastern South Dakota. Botanical Gazette, vol. 46, 1908, p. 83.

field previously investigated in Woodbury, Monona, Harrison, and Pottawattamie counties, Iowa. Unexpected results, reaching beyond the limits of the original assignment, were obtained, and they are here presented with some hesitation, because they contradict several of the conclusions which have been reached concerning the geology of the area under discussion by the experienced geologists whose works have been cited. It is comforting to know, however, that one of these contradicting conclusions, namely, that the Wisconsin is wholly absent from the western part of Lyon County, Iowa, was also reached independently and coincidently by Professor J. E. Carman, of the Iowa Geological Survey.

A brief description of the topography of the region may assist in the interpretation of its geology.

Topography

Topography no doubt played an important part in determining the conclusions which had been previously reached concerning the drifts of the Sioux Falls region, for it presents peculiarities and variations of such nature that were topographic factors made the sole criterion by which the age of a drift sheet is determined they would cause a division of the area between two distinct Glacial epochs, and this division would not coincide with stratigraphic structure which may be determined in sections.

These topographic peculiarities have already been shown on the map, plate III, accompanying Wilder's report (1900), and on the maps in Todd's Elkpoint folio (1908), but a brief description of them may make them more striking in their relation to the geological problems involved.

The Big Sioux River forms the boundary between Iowa and South Dakota in the greater part of the territory under discussion. (See map, figure 1.)

FIGURE 1.—*Map of Sioux Falls and Vicinity*

K, Kansan drift; L, loess; A, Aftonian; S, sand and gravel exposures of doubtful age
The dotted areas represent gravel terraces

On the Iowa side the valley is bordered by hills, which vary in height and ruggedness of vertical contours. Near the northern boundary of the State and thence to the valley of Bloody Run they are rather low, and ascend quite gradually to a height scarcely exceeding 150 feet above the valley. South of the creek, and particularly south of the Chicago, Rock Island and Pacific Railway, the surface is much more broken and the bluffs are more abrupt. This rough topography follows the river valley on the Iowa side to Beloit, opposite Canton, and throughout this portion of the territory the rugged hills on the Iowa side rise to a height of from 100 to 150 feet above the flat plain, which here extends along the river on the South Dakota side. (See plate 7, figures 1 and 2.) Near the river these ridges are often deeply cut by a bewildering series of narrow ravines, with steep slopes, often more or less wooded, but eastward they gradually merge with the rolling prairie topography, which characterizes the greater part of the surface of Lyon and Sioux counties. Northward this series of ridges and hills is continued along the west side of the Big Sioux from a point opposite Bloody Run to the great bend near Sioux Falls, this being the part referred so frequently to the Altamont moraine.

On the South Dakota side south of this ridge a great plain, gradually sloping to the south and east, extends along the river to a point less than 3 miles south of Canton. This plain is in some places, especially northward, cut by narrow valleys or gorges, often to a depth of 50 or 60 feet, but at a little distance these are not visible, and a view of the area leaves the impression of a continuous level plain. The Chicago, Rock Island and Pacific Railway follows such a narrow valley from the Big Sioux River almost to Shindlar, and many other such valleys may be seen in the same vicinity. Southward the plain is a little lower and these valleys are less prominent, though even this portion of the plain is well drained.

At several points the level of the plain is interrupted by knobs or ridges, which rise abruptly from the general level. One of these is located near the northeast corner of Canton. Another, much more prominent, occupies portions of sections 5, 6, 7, and 8, township 98 north, range 48 west, about two and one-half miles northeast of Canton. (See plate 7, figure 2.) A third is located in sections 19 and 20, township 99 north, range 48 west. These knobs have been regarded as a part of the Altamont moraine, as has been noted.

South of this Canton plain the rugged, timbered hills extend east and west along the south side of the Big Sioux, the hills on the Iowa side being less abrupt, but at Fairview the line of rough hills again crosses to the Iowa side, though the South Dakota side remains somewhat rough and elevated to a point nearly opposite Westfield, Iowa.

FIGURE 1.—BLUFFS SOUTH OF GRANITE, IOWA
The lower plain is on the Dakota side, looking south

FIGURE 2.—KANSAN KNOB NORTHEAST OF CANTON
Kansan plain to the right, looking west

RIDGES NORTHEAST OF CANTON, SOUTH DAKOTA

Special emphasis has here been placed on that portion of the area along the Big Sioux River between Iowa and South Dakota, because specific references have so often been made to its special topographic features in determining the location of a part of the so-called Altamont moraine. However, the region in the immediate vicinity of Sioux Falls is of equal interest.

The Big Sioux River here forms a great double bend, first passing southward west of the city, then abruptly turning northeastward through the city to a point about 3 miles north of west from Brandon, and again abruptly turning east and then south to the northwest corner of Iowa and southward.

These striking deflections from the general southerly course of the stream are due to prominent topographic features of special interest. As previously noted, the ridge opposite Granite, which has been mapped as a part of the Altamont moraine, extends in a northerly and northwesterly direction toward Sioux Falls. Its northerly portion consists of an elevated plateau, more or less broken in the ordinary manner of rougher Kansan surfaces, and terminates in a series of very rugged ridges and knobs northeast of Sioux Falls in the eastern lobe of the double bend. A portion of this rough area is illustrated in plate 8, figure 1. The greater part of this plateau reaches an altitude of nearly 150 feet above the valley, but its most rugged portion northward rises fully 220 feet above the river.

The roughest portion, lying in and near the northeast corner of township 101 north, range 49 west, consists of a bewildering maze of sharp, mostly gravelly, ridges and knobs separated by deep ravines. Its northern and northwestern borders are very abrupt, as shown in the figure, but southward and southwestward it gradually merges with the less broken general surface of the plateau, or broad ridge, which passes around the south side of the western bend of the Big Sioux River.

Northward from the very rough area north of the river the uplands appear to be somewhat lower, but the surface is broken in characteristic Kansan fashion, and a portion of this topography is projected southwestward into the western lobe of the great bend in the form of a narrow ridge, which passes through the city of Sioux Falls, as shown on the map.

South of the western bend of the river there is a broad ridge, extending westward and here forming the bluffs of the river, which is also more or less broken. Some parts of it rise nearly 150 feet above the river above the falls. This ridge was followed only to a point south of the

west side of Sioux Falls. It seems to extend in a westerly direction for some distance.

Below the western bend of the river the valley is narrow for several miles, its narrowest portion lying in the city of Sioux Falls, where it scarcely exceeds half a mile in width. Above this bend, along the west line of Sioux Falls and northward, the valley widens to more than 2 miles, and the bluffs on either side of the flat bottom land are low and rounded. West of this part of the valley the bluffs rise only about 50 feet above the valley, and the region to the west and northwest presents a gently but distinctly rolling surface. The difference between the parts of the valley above and below Sioux Falls is very striking.

Another topographic feature of interest is presented by the high benches, with boulder slopes, which may be seen along the narrower part of the valley as far down as East Sioux Falls, and also along the valleys which cut the upland between Sioux Falls and East Sioux Falls. These benches rise to be about 130 feet above the river below the falls, and are usually capped with a layer of gravel and boulders, or sometimes silt. Where boulders strew the slopes of these benches, as shown in plate 8, figure 2, they are apparently derived from the capping stratum. These benches are most prominent east of Sioux Falls and north of East Sioux Falls.

The valley of the river also presents several features of interest. No doubt the chief of these are the gravelly and bouldery terraces, which are very striking and which often closely crowd the river, so that its immediate valley is very narrow. This immediate valley is frequently bordered by alluvial deposits, consisting of silt and sand, with numerous shells of modern fresh-water mollusks.

On the Iowa side the most prominent terraces or benches are those at Granite and Klondike. The Granite terrace rises 40 to 50 feet above the Big Sioux bottoms, and is cut in its southern part by Bloody Run and by the Chicago, Rock Island and Pacific Railway. It does not follow the valley of the creek, though small terraces are found, and the valley is much broader above Granite than it is just below, where it enters the great terrace or bench. It appears quite flat, but its surface is broken by mostly shallow drainage channels. That part of it which lies north of the railroad and from one to one and a half miles west of Granite has its surface varied by about 100 boulder and gravel covered mounds, which average about 5 or 6 feet in height and 50 feet in diameter. Two of these are represented in plate 9, figure 1. Wilder (1900, page 140) ascribes to them a morainic origin, but they are clearly burial mounds or

FIGURE 1.—GRAVELLY RIDGES NORTHEAST OF SIOUX FALLS

FIGURE 2.—UPPER BENCH IN WEST HALF OF SECTION 1
Township 101 north, range 41 west

TOPOGRAPHIC FEATURES NEAR SIOUX FALLS, SOUTH DAKOTA

refuse heaps, for even a superficial examination and slight excavation revealed the presence of human bones and teeth, flint implements, broken pottery, the split bones of bison and deer, mussel-shells, and other evidences of human agency. Superintendent David H. Boot, of Canton, who made a section of one of these mounds, found skeletons buried in a looser stratum under a surface covering of several layers of gravel and boulders. Interment took place on the natural surface, and all the materials of which the mound was constructed were evidently carried from a distance.

Mounds are also common on all the prominent elevations of this region on both sides of the river.

The Granite terrace extends northward to the State line, where the Sioux quartzite comes to the surface, and southward it is prominent for 2 miles below the railway.

The Klondike terrace occupies a large part of sections 7, 8, 9, 16, 17, and 21, and rises 25 to 40 feet above the river bottom. This is also deeply cut by creeks at both its northern and southern extremities, but the greater part of the plain is quite level, though shallow erosional drainage channels are common. Less distinct terraces also appear at and below Beloit.

The South Dakota side also presents numerous and extensive terraces, but very frequently these blend with the flat plain, which is here prominent, and it is then difficult to determine their limits. They are especially prominent between section 1, township 99 north, range 49 west, and Canton, and again below Fairview.

North of the Iowa State line the gravel terraces lie on the east side of the river, and are here a continuation of the Granite terrace, but they are interrupted at the state line by exposures of Sioux quartzite and at other points by tributary streams. The terrace opposite East Sioux Falls is prominent for some distance, but its eastern limit was not determined.

Another prominent bench or terrace is located west of Brandon, within the east lobe of the great bend of the Big Sioux. The Chicago, Minneapolis, St. Paul and Omaha Railway follows it for more than 2 miles. The limits of the terrace at Brandon were not determined.

A narrow terrace also extends along the west side of the east bend of the river just below Sioux Falls, and a large terrace island is located on the south side of the river, in part in the northeast portion of Sioux Falls. These terraces will receive further attention.

So far as could be observed, there were no terraces in the broad valley of the Big Sioux above Sioux Falls.

Geology

IN GENERAL

The Pleistocene formations of this region constitute its most interesting and conspicuous feature. In the northern part they rest directly on the Sioux quartzite, and southward to Sioux City they overlie the Cretaceous. The following members are represented: Nebraskan drift; Aftonian gravel, sand and silt; Kansan drift; a bluish gray post-Kansan loess, a later yellow loess, and ordinary alluvium, which needs no discussion.

Practically every exposure between the northwest corner of Iowa and Fairview was examined, in most cases more than once, with remarkably consistent results. The sections of greatest interest naturally fall into two groups: the bluff sections, which are found in the rougher portions of the area, and the bench or terrace sections along the streams. A few typical sections are here presented.

BLUFF SECTIONS [12]

1. *Fairview section.*—One and one-half miles west of Fairview, in section 16, on the south side of the river, a slide reveals the following section:

> Loess, capping the hills above.
> Kansan, 15 feet exposed.
> Aftonian:
>> Alternating layers of silt and sand, 10 feet.
>> Coarser sand and fine gravel, 10 feet.
>> Nebraskan, 2 feet exposed, its top 45 feet above the river bottoms.

The Nebraskan is here very hard, jointed, in part gray, somewhat ferruginous, and with very dark carbonaceous materials in the upper part. The Kansan is typical, bluish, calcareous joint-clay, with ferruginous streaks and cloudings, and some pebbles and small boulders, being exactly like the ordinary Kansan, which may be traced in a complete series of exposures from northern Missouri and southern Iowa to the region under discussion.

The Aftonian is also typical, and its position between the Nebraskan and Kansan drifts is unmistakable.

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[12] The numbers of these sections appear on the map.

FIGURE 1.—INDIAN MOUNDS WEST OF GRANITE, IOWA

On bench, or terrace

FIGURE 2.—SECTION OF TERRACE NEAR NORTH LINE OF SECTION 17, TOWNSHIP 99 NORTH, RANGE 48 WEST

a, Nebraskan; *b*, gravel and bowlders

FEATURES OF THE BIG SIOUX RIVER TERRACES

2. *Section four and one-half miles west of Fairview.*—This section is located in the bluff near the north line of section 18, township 97 north, range 49 west.

> Kansan, 10 feet exposed.
> Aftonian:
>> Silt containing fragments of shells, about 10 feet.
>> Sand, about 15 feet.

The base of the Aftonian appears to be about 75 feet above the river bottom, but the lower part is slumped and the base could not be determined. Copious springs flow from the Aftonian along these bluffs.

3. *Beloit section.*—This is located in section 19, northeast of Beloit, Iowa, opposite Canton. It was formed by a land-slide and shows the following members:

> Yellow loamy material, probably loess overwash, 5 feet.
> Kansan drift, typical, with boulders, 27 feet exposed.
> Aftonian sand, 13 feet.
> Nebraskan drift, rising 65 feet above the river, its upper 30 feet clearly exposed.

The Kansan and Aftonian are separated by a sharp, ferruginous line, and the Aftonian has a layer of cemented sand, 2 inches thick, at its base. The Nebraskan is typical blue-black till, with its uppermost 5 or 6 inches very ferruginous.

Aftonian and Nebraskan appear at other points between this section and the bend of the river to the east.

4. *Section in the southwest quarter of section 33, township 99 north, range 48 west.*—This section has been exposed by a land-slide, and is located on the Iowa side of the Big Sioux. The north side of this exposure shows:

> Kansan, 15 feet exposed, but Kansan boulders strew the hillside for 85 feet above the section.
> Aftonian, chiefly sand, with a few lines of pebbles, capped with about 2 feet of silt containing shells, 10 feet.
> Nebraskan, typical blue-black till, with a large number of boulders, 60 feet.

This is the finest section of Nebraskan which has yet been discovered, and the exposure is clear for fully 60 feet, its base disappearing in the river. The Nebraskan here contains an unusually large number of boulders and portions of it are coarsely jointed. This is probably what has

been considered older Kansan in this general region, but its position below a fossiliferous silt and sand and its dark color indicate that it is Nebraskan. Some of its portions are certainly like the coarser Nebraskan at Council Bluffs and Omaha.

The Aftonian silt, which is sharply set off from the Kansan drift above, but blends with the Aftonian sand below, is whitish, very calcareous, and contains shells of fresh-water mollusks of the usual Aftonian type.

The Kansan is typical, and at the very top of the ridge is covered with a thin layer of yellow loess. The slopes are liberally dotted with Kansan boulders.

Other sections appear both above and below section 4.

5. *Section south of Klondike, Iowa.*—This is located in Lyon County, in section 21, township 99 north, range 48 west, at the point of the bluff south of the creek below Klondike. It presents the following:

Kansan, typical, 15 feet exposed.
Aftonian:
  Loose sand and gravel, about 24 feet.
  Conglomerate, forming a projecting ledge, 5½ feet.
  White, calcareous, marly stratum, probably Aftonian, 5 feet.
Nebraskan, typical, more or less exposed to creek, 15 feet.

This Aftonian is on a level with the bed of gravel in the near-by terraces.

Another exposure just east shows about 40 feet of Kansan, with numerous sand boulders and sand lenses, especially in the lower part, indicating that the Kansan plowed the Aftonian sands.

6. *Peterson section.*—This is located on the west side of the river just above Klondike. Here a bed of apparently Aftonian sand and fine gravel rises to a height of 20 feet above the river bottoms and is covered by a mass of typical Kansan, which evidently forms the bulk of the bluff. Along the line of contact the Kansan and Aftonian are more or less mixed.

This section is opposite the great Klondike terrace.

Several exposures along the bluff above the Peterson section show Aftonian, which in some cases reaches a height of over 30 feet above the bottom lands. This is uniformly below Kansan drift and gives rise to numerous springs.

7. *Nicholson bridge section.*—This is located east of the Nicholson bridge, in section 6, township 99 north, range 48 west, Lyon County, Iowa. It shows:

Kansan, several feet exposed.

Oxidized band, 6 to 8 inches.

Aftonian sand (probably), 20 feet.

Nebraskan, typical, several feet exposed, its top 30 feet above the river bottoms.

This section is opposite a gravelly bench or terrace, which is covered at least in part with Kansan drift.

8. *Exposure in section 1, township 99 north, range 49 west.*—This exposure is located in Lyon County, Iowa, in the rugged bluffs, the southern portion of which is represented in plate 7, figure 1. There was here evidently much plowing of the Aftonian sand by the Kansan ice, for the former has been forced up to a height of 140 feet above the valley. Kansan rises above this for at least 35 feet. Nebraskan rises to a height of 125 feet in these bluffs and springs appear above it.

9. *Bankson bluff section.*—This is located in the northeast quarter of section 2, township 99 north, range 49 west, on the face of the river bluff, and is nearly opposite section 8.

Kansan, weathered on exposed faces, probably 35 feet.

Aftonian:

Coarse sand and fine gravel, 8 feet.

Conglomerate, 3 feet.

The conglomerate is about 75 feet above the valley, and a fine spring discharges above it.

10. *Bankson cellar and well section.*—This is of especial interest because it is on the great plain which extends from Shindlar to Canton, and shows the structure of what had probably been formerly included in a Wisconsin plain.

A well and cellar dug near the residence of Mr. Bankson show the following:

Soil and yellowish weathered Kansan, 2½ feet.

Kansan, typical, 7½ feet.

Aftonian:

Sand, about 1 foot.

Conglomerate, thickness unknown.

Springs flow from about the level of the conglomerate on the gentle slope of the hill.

11. *Springdale township sections.*—These sections, three or four in number, are located on the west side of the Big Sioux above the Chicago,

Rock Island and Pacific Railway bridge west of Granite, at points where the river comes in contact with the bluffs, causing a slumping. They are of special interest because they are located near or on the side of the ridge which has been referred to the Altamont moraine, and show its structure. All show typical Kansan above, which was also traced to the summit of the ridge, and the southernmost, the first north of the railway bridge, shows a band of sand near the base resting on a stratum which appears to be Nebraskan.

The most interesting section in this series is located at the base of the northward extension of this ridge at the Louis Egge house, opposite and just south of the Iowa State line. Below this point ledges of Sioux quartzite rise fully 40 feet above the river valley. Between the house and these ledges numerous springs flow from beneath the Kansan drift-covered slopes. A fine section, marked on the map, is exposed on the south side of the small creek a few rods west from the slopes of the main bluffs facing the river. It presents the following members:

Kansan drift, typical, bluish, calcareous; 6 feet exposed, but appearing at greater elevations on the slopes above.

Silt, grayish and ferruginous, 8 to 12 inches.

Coarse sand, cross-bedded, water-bearing, more or less slumped, 7 feet.

A very dark bed of heavy, tough material appears in the bed of the creek at the base of the section. This is probably Nebraskan drift.

The silt and sand are evidently Aftonian, and the entire section closely resembles some of the clearest sections along the Big Sioux and Missouri rivers in both structure and relative position of the members.

Another bluff section which is worthy of note in this connection lies to the south of our territory, but belongs to the series of exposures which may be traced to and along the bluffs of the Missouri River. It is known as:

12. *Otis mill-site section.*—This section is located in the bluffs on the west side of the Big Sioux River opposite Chatsworth, Iowa. While it is somewhat remote it belongs to this general region and has been discussed by both Todd and Wilder.

It shows a bed of dark fossiliferous silt resting on the Cretaceous; above it is an irregular stratum of ferruginous gravel, and resting on this is a thick bed of typical Kansan drift covered with loess.

Todd (1908) reports a lower jaw of a fossil horse and many fresh-

water shells from the silt. The writer collected the following species of mollusks in this stratum:

Planorbis bicarinatus.	*Amnicola* ......
Planorbis dilatatus.	*Pisidium* ......
Segmentina armigera.	*Sphærium sulcatum.*
Physa gyrina.	Unio (?) fragments.
Lymnæa reflexa.	*Pyramidula striatella,* 1 specimen.
Lymnæa humilis Say (?).	*Strobilops,* fragment.
Valvata tricarinata.	

The last two are terrestrial and were evidently washed in.

This fauna is such as occurs in the Aftonian elsewhere, and this, together with the stratigraphic position, indicates that the silt, and probably the gravel, are Aftonian. Moreover, this, with the other bluff sections described in this paper, is only a part of the series of sections which may be traced southward along the bluffs of the Big Sioux and the Missouri rivers to Sioux City and southward. All of these sections show the same characteristics as those which were determined by the writer in Harrison and Monona counties.[13]

SECTIONS AT SIOUX FALLS

Several interesting sections occur within the limits of the city of Sioux Falls. They are of special interest because they lie within the so-called Altamont moraine. A brief discussion of several of these sections follows:

13. *Illinois Central Railway section east of Sioux Falls.*—This includes the first two contiguous cuts along the Illinois Central Railway 1 mile east of Sioux Falls. These are the cuts described by Todd and Wilder.

The thickness and character of the strata in these sections are somewhat variable, but the first or west cut shows a complete section on the northeast side as follows:

Sandy, somewhat loess-like stratum, possibly æolian, 2 to 5 feet.
Gray, weathered drift, probably Kansan, 7 to 9 feet.
Gravel, sand, and silt:
  Sand, gravel, and boulders, 1 to 2 feet.
  Silt, with sand and pebbles, ferruginous, 2 to 4 feet.
  Sand, gravel, and boulders, 5 to 6 feet.
Weathered gray drift, probably Kansan, 2 feet exposed.

The southwest side of the cut is similar, but the upper Kansan (?) is thicker, tougher, and less weathered.

[13] See Harrison and Monona counties report, Iowa Geological Survey, vol. xx, 1911.

The second cut is connected with the first and lies east of it. A portion of it is shown in plate 10, figure 1. On the northeast side it presents the following members:

c. Sandy yellow stratum, possibly æolian, 4 to 5 feet.
b. Gray, weathered Kansan (?), 4 to 6 feet.
a. Gravel, sand, and silt, the latter predominating:
Sand, gravel, and silt, 2 feet.
Dark fossiliferous silt, about 6 feet.
Gravel and boulders, stratum ferruginous, irregular.
Weathered drift, probably Kansan, exposed at base.

Three molars of *Equus scotti* were collected at the base of the fossiliferous silt, and fragments of bones were scattered through it. Near the east end mollusk shells are very abundant and the following were collected:

**Planorbis bicarinatus* Say.
**Planorbis parvus* Say.
Planorbis dilatatus Gld.
Ancylus rivularis Say.
**Valvata tricarinata* Say.
Amnicola ......
Segmentina armigera (Say) H. and A. Ad.
**Physa integra* Hald.
Physa sayi (?).
Lymnæa reflexa Say.
**Lymnæa caperata* Say.
Lymnæa humilis Say (?).
**Pisidium compressum* Prime.
Pisidium abditum Hall (?).
**Sphærium sulcatum* Lam.
Anodonta, probably *A. imbecillis* Say.
**Vallonia costata* Sterki, 1 specimen.

The last species only is terrestrial.

The species marked with an asterisk were reported in Todd's paper (1899), *Physa integra* appearing under the name *Physa heterostropha*. This fauna is identical with that of the Aftonian.

In the first cut this silt is replaced by sand, gravel, and boulders.

14. *Hamilton sand pit.*—This pit is located south of the Illinois Central cut on the east side of the same ridge. It presents the following section:

Heavy ferruginous, bluish joint clay, evidently Kansan, 7 feet.
Cross-bedded sand and fine gravel, 10 feet exposed.

Mr. Hamilton reports that the sand stratum is about 25 feet deep. He states that when digging a well near by he penetrated into a hard dark-blue clay, possibly Nebraskan.

15. *Collins sand pit.*—This is located near the third cut from the west along the Illinois Central Railway, opposite the Hamilton pit. The section is as follows:

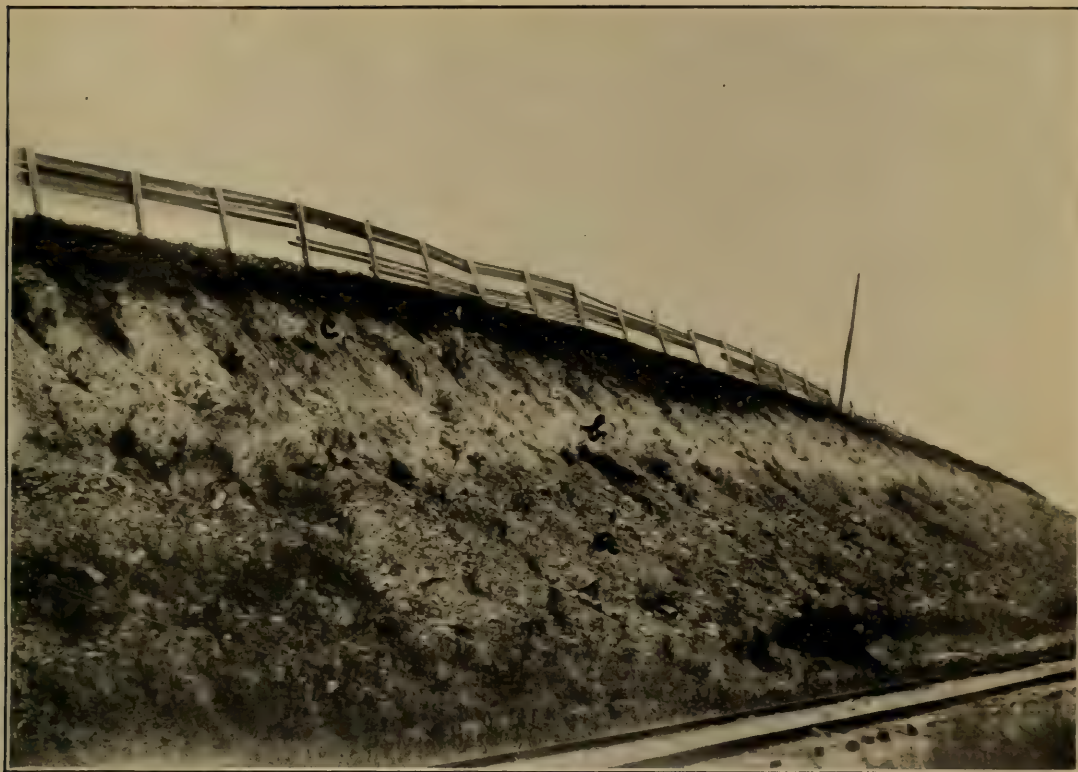

FIGURE 1.—SECOND ILLINOIS CENTRAL CUT EAST OF SIOUX FALLS

a, silt, fossiliferous; *b*, weathered drift (?); *c*, sandy loess-like stratum

FIGURE 2.—KANSAN OVERLAIN BY SILT

a, Kansan drift; *b*, gray silt; *c*, yellowish silt or loam

SECTIONS IN SIOUX FALLS, SOUTH DAKOTA

Bluish joint clay, capped with soil, evidently Kansan, 6 feet.
Sand and gravel:
  Gravel, 6 feet.
  Sandy silt, 3 to 5 feet.
  Cross-bedded sand and fine gravel, 4 to 5 feet exposed.

Fragments of a shell, probably *Unio*, and a valve of *Sphærium sulcatum* were obtained from the lower sand. Mr. Collins also found a molar of *Equus scotti* and a molar of *Castoroides* in the lower sand and gravel of this pit.

The top of the gravel in this pit is about on a level with the top of the fossiliferous silt layer in the second Illinois Central cut.

Other pits in the vicinity show cross-bedded sand and gravel.

16. *Road-cut in section 14, township 101 north, range 49 west.*—This cut is just east of the Illinois Central Railway. It is of interest because it further illustrates the irregularity of the strata of this region. On the south side of the wagon road a large sand boulder is included in blue joint clay, which is evidently Kansan drift, and on the north side Kansan drift and sand and gravel are irregularly folded.

Other sections in the vicinity still further emphasize this irregularity. The road-cut just east of section 15 shows an irregular interstratification of Kansan drift, sand, silt, gravel, and boulders, and only a few rods east of that, on the north side of the road, a well-boring near Mr. Danbury's house showed about 10 feet of drift (?) and then about 75 feet of fine sand. It is difficult to find two sections in this immediate vicinity which present the same materials arranged in the same relation to each other.

The sections on the north side of the river in Sioux Falls almost uniformly show Kansan drift overlain with a stratum of sandy silt or, more rarely, sand and gravel. A typical section is illustrated in plate 10, figure 2. This section is located on the east side of Dakota Avenue, south of Russell Street, and presents the following members:

c. Yellow (or nearly black) silt, or in part æolian, 1 to 1.5 feet.
b. Gray, sandy silt, laminated, with occasional bands of sand or fine gravel, 1.5 to 2 feet.
a. Kansan drift, 5 feet exposed.

Occasionally in these sections irregular layers of sand and gravel occur in the drift, as on the east side of McClellan Street opposite Main Avenue, and at several points a dark-gray silt, similar to the fossiliferous silt in section 13, is irregularly disposed in the Kansan drift. The lower part of the McClellan Street cut shows such a mass (containing some pebbles

and broken shells), fully 20 feet long and 4 or 5 feet deep, and presenting the appearance of having been pushed by drift moving from the north. Another mass of similar silt occurs in Kansan drift on the west side of Dakota Avenue, north of West Third Street. Here a mass of dark silt, in places more than 3 feet deep, is exposed for fully 75 feet. This mass dips downward to the south, and evidently is not silt deposited *in situ,* but moved by Kansan ice.

TERRACE OR BENCH SECTIONS

The foregoing sections, and many others like them, show the structure of the Pleistocene of the uplands, but there are also sections in the terraces, or benches, which are so conspicuous in the Big Sioux Valley. The more conspicuous terrace sections are here discussed in detail.

17. *Fairview gravel pit.*—This is located along the Chicago, Milwaukee and Saint Paul Railway, 1 mile south of Fairview, South Dakota. Here 30 feet of gravel rest on a bed of tough, typical blue-black Nebraskan drift, which is separated from the gravel by a tough, reddish, laminated silt-band. The Nebraskan is blue-black, tough, and contains planed boulders.

18. *Klondike section.*—This is located in a gully in the terrace just east of Klondike bridge, and shows 20 feet of cross-bedded sand and gravel, with the uppermost 2 or 3 feet crowded with boulders, resting on a bed of gray, in part blue, very tough joint-clay, which is probably Nebraskan. Springs flow abundantly from the gravel.

19. *Section west of Klondike.*—This is located on the west side of the river opposite Klondike. It follows the edge of the bench or terrace and shows an exposure of 15 feet of typical blue-black Nebraskan, on which rest about 10 feet of sand and gravel. This is then covered with soil to a depth of 1 to 2 feet. This is one of the finest exposures of Nebraskan observed in South Dakota. Along almost the entire length of this exposure springs flow freely from the base of the gravel.

20. *Sections along the north side of section 17, township 99 north, range 48 west.*—These sections, three in number, are exposed along a small creek about a mile northwest of Klondike, and show gravel resting on a gray or blue-black pebble-bearing Nebraskan (?). The eastern section, shown in plate 9, figure 2, shows a bench of typical blue-black Nebraskan, 4 to 5 feet exposed, supporting a bed of coarse gravel 4 to 5 feet thick. The westernmost section shows a hard gray bed, probably Nebraskan, exposed about 2 feet at the base, and on it there is a conglomerate stratum about 2 feet thick, on which rest 6 to 15 feet of loose gravel. Numerous springs flow from the gravel.

21. *Granite gravel pit.*—This is a railway pit located at the edge of the Granite terrace on the north and east side of Bloody Run, about a mile west of Granite. Near the south end it presents the following section:

A gravelly yellowish stratum of uncertain age, 3 to 6 feet.
Bed of sand and gravel, 3 to 5 feet.
Weathered grayish drift, probably Kansan, 5 feet exposed.

A worn fragment of the molar of a horse was found in the gravel bed.

This is just opposite that part of the terrace which Wilder represented as a portion of the Altamont moraine, and probably has the same structure, being cut off only by the narrow valley formed by Bloody Run.

The valley of Bloody Run east of Granite contains beds and banks of gravel which may be more recent. There are numerous evidences of water action at and east of Granite and in the first railway cut west. The immediate valley of the creek is very narrow just west of Granite, and the peculiar topography, together with the presence of stratified beds at and east of Granite, might suggest a damming of the creek at a point just west of Granite.

The valley of this and other tributaries of the Big Sioux River should be studied more fully.

Satisfactory sections were not found on the terraces above the Iowa State line. The great terrace west of Brandon is largely made up, at least in its western part, of gravel, but along the wagon road it also shows a silt overlain by 4 to 6 feet of loess-like material. The latter does not occur excepting where there is underlying silt and it blends with it more or less.

The gravel pit on the south side of the terrace island at Sioux Falls shows cross-bedded sand and gravel, with a thin covering of a yellow sandy material, which is probably in part æolian.

PLEISTOCENE FORMATIONS

The Pleistocene formations as exhibited in our territory are here discussed somewhat more in detail.

Nebraskan drift.—As noted in the several sections, the Nebraskan drift is exposed at numerous points on both sides of the Big Sioux River in both Iowa and South Dakota.

It most frequently appears in the form of a blue-black, very tough, impervious joint-clay containing scattered boulders and pebbles and usually breaking up on drying into very small "joint" fragments. Sometimes it contains ferruginous bands and streaks, and the uppermost por-

tion is frequently separated from the overlying Aftonian by a thin layer of laminated, silty material of similar toughness, the latter being gray (as if weathered) or sometimes ferruginous. A similar laminated layer sometimes separates the Aftonian from the underlying Cretaceous shales when the Nebraskan is missing, as in the exposures near Chatsworth and at other points just south of our territory. It is probable that much of the finer Nebraskan drift material was derived from the dark Cretaceous shales. In exceptional cases numerous boulders, large and small, many of them planed, are scattered throughout the formation, as in the exposure in section 33, township 99 north, range 48 west, in Lyon County, Iowa. The very tough whitish or light gray stratum which appears under sand and gravel in several sections probably also belongs with the Nebraskan.

While the Nebraskan of this region sometimes presents the gray phase, the greater part of it is dark and tough. It is also somewhat variable in the coarseness of fracture, but not more so than the Nebraskan (sub-Aftonian) of Afton Junction, Council Bluffs, and other points where the older drift has been recognized; indeed, it seems to be identical with the latter in all respects.

The Nebraskan of this region is very variable in thickness. As noted, the finest exposure which the writer has thus far found here or elsewhere is that which was formed by a land-slide in the Big Sioux River bluffs in section 33, township 99 north, range 48 west, in Lyon County, Iowa. Here fully 60 feet of typical blue-black Nebraskan, containing, however, an unusual number of boulders, are exposed. In the Beloit section about the same thickness is somewhat less clearly exposed. In section 8, in the Big Sioux bluffs, Nebraskan was found at a height of 125 feet above the river, but both the Nebraskan and the Aftonian at this point show evidence of disturbance, and were probably plowed up by the Kansan ice-sheet, which left its burden of drift on the summit and northeast slope of the ridge. Evidence of such plowing may also be seen in some of the sections near Sioux Falls.

Other sections present smaller exposures of this drift, but it is evident that the sheet is still quite thick.

Aftonian interglacial deposits.—The Aftonian as interpreted in this region is exposed in the bluff sections and consists of silts (usually gray), sand, gravel, and boulders. While the silt when present usually forms the uppermost member of the formation, an examination of the section records herein presented will show that there is no fixed relative position of the silt, sand, gravel, and boulders, but that they are variously disposed. The coarser materials are usually more or less distinctly cross-bedded,

often ferruginous, and frequently contain streaks and cloudings of MnO_2, and may be consolidated to form conglomerate.

In referring these deposits to the Aftonian the writer is conscious of the danger of confusion which may arise from the presence of gravels, sands, and silts in other Pleistocene formations. There are beds of sand and gravel in the Kansan, and the mere fact that one finds Kansan drift overlying a bed of gravel does not prove that the gravel is Aftonian. However, in the region under discussion the bluff sections consistently show the beds designated as Aftonian below the Kansan and above the Nebraskan. That they do not belong to either of these drifts is shown again by the presence of fossils in the Otis mill-site section and sections 2 and 4 of our series. These sections also clearly show the position of the fossiliferous beds between two different drift sheets, the lower of which is Nebraskan and the upper Kansan. In these sections the fossiliferous sections are so extensive and so regular that they can not be regarded as masses incorporated in the drift during its advance, such as those which occur in some of the Sioux Falls sections. In structure, composition, and contents, as well as in stratigraphic position, these fossiliferous deposits are in all respects like the Aftonian beds of western Iowa.[14]

There is greater doubt concerning the identity of the bluff sands and gravels which contain no fossils. In some cases, as noted, there is evidence that the present position of the beds has been determined by the action of the Kansan ice, and there are other bluff sections of limited extent in which exact relations can not be satisfactorily determined. However, the evidence of the fossiliferous sections, together with the consistent position of the members of the fossiliferous and non-fossiliferous sections, is sufficiently conclusive to warrant the conclusion that in all these bluff sections the silts, sands, and gravels are Aftonian or, where disturbed by Kansan ice, at least of Aftonian origin.

Aftonian in the Sioux Falls sections.—It was the opinion of the writer, expressed when the first draft of this paper was prepared, that the silt, sand, and gravel beds in sections 13 to 15, at Sioux Falls, represent Aftonian in place. Subsequent investigations led to a change of opinion. Attention has been called to the remarkable confusion of Pleistocene strata which is revealed in the sections south of the river. In the vicinity of section 15 and eastward much evidence of mixing and plowing is presented. In the western part of section 13 the gravel bed is somewhat

[14] See the writer's papers in the Bulletin of the Geological Society of America, vol. 20, 1910, pp. 399-408, and vol. 21, 1910, pp. 119-140. Reports of the Iowa Geological Survey, vol. xx, 1911 (1910), pp. 309-366.

tilted, with gray drift beneath it. In the eastern part of the same cut a thick bed of fossiliferous silt occupies about the same position, but the gravel and silt are not continuous, nor do they seem to be conformable.

The arrangement of the strata in this section has been a puzzle for a long time. In the light of the evidence of the McClellan Street and Dakota Avenue silt masses, already described, it is easy to conceive of the silt and sand in sections 13 to 16 as displaced by Kansan ice. The amount of such displacement by glacial ice has probably been generally underestimated and will be discussed in a subsequent paper.

Briefly, it is the writer's present view that the fossiliferous silt and sand beds in sections 13 to 15 are of Aftonian origin, but displaced by Kansan ice, and that therefore the fauna of these beds is truly Aftonian. It should be noted that every species of fossils, both mammalian and molluscan, is found also in the Aftonian beds of western Iowa.

Kansan drift.—Characteristics of the two types.—Kansan drift has been incidentally discussed in connection with the older Pleistocene formations, and its occurrence in specific exposures is recorded in the list of sections.

In this region it presents two ordinary types: The unweathered, bluish, calcareous, heavy joint-clay, with pebbles and boulders and with ferruginous streaks and cloudings, and the softer, gray weathered type, with occasional ferruginous lines and mottlings.

The first is the more common and covers largely both the hills on the Iowa side and near Sioux Falls and the plain between Shindlar and Canton. It also makes up or covers the knobs north and northeast of Canton and west of Granite on the South Dakota side, which have been regarded as a part of the Altamont moraine. There can be no question concerning the identity of this drift unless *all* the drift of western and southwestern Iowa, northern Missouri, and eastern Nebraska is something other than Kansan drift, for in all respects this drift is exactly like that in the regions mentioned.

Additional evidence that this is truly Kansan is found in the fact that much of this drift is covered with two loesses, one bluish gray, older; the other yellow and younger. In several hundred sections in Indiana, Illinois, Wisconsin, Missouri, Iowa, Nebraska, South Dakota, and Minnesota, in which two loesses are shown, which the writer has examined in recent years, he has never found the bluish gray (post-Kansan) loess in any other position than immediately above the Kansan, or its immediate derivatives represented by the Ferreto and the Loveland joint-clay and probably the Buchanan gravels, excepting in a few instances where there

was manifest evidence of later disturbance. No other formation ever intervenes, so far as observed, and it is not within the range of probability that any other formation will ever be found in this intermediate position. In view of this fact it is reasonable to conclude that the drift which here so frequently lies immediately under the older loess is Kansan.

Perhaps the most puzzling feature of the Kansan in this area is its occurrence on both the plain south of Sioux Falls on the South Dakota side of the Big Sioux River and on the opposite Iowa uplands, which rise more than 150 feet higher. The writer is not prepared to give an explanation of the fact, but suggests that it may be found in advances of the Kansan ice-sheet at different times and in different directions on opposite sides of the Big Sioux valley, in our territory. There is evidence that such different movements did occur. The generally accepted opinion is that a great part of the western Kansan sheet moved in a southwesterly direction, yet on the plain in question there was undoubtedly a movement in a southeasterly direction. On the flat area near the state line, on both the Iowa and South Dakota sides, which is practically an extension of the plain on the west side of the river, there are numerous glacial striæ on the Sioux quartzite, which here comes to the surface over large areas. The striæ of one of these sets extend in a direction varying from north 10 degrees to 15 degrees west, and those of the other set vary from north 30 degrees to 40 degrees west. Similar striæ having the same general direction appear on the Sioux quartzite at the foot of the slope north of section 16, at Sioux Falls. The general direction of the movement of the ice-sheet which passed over the plain was therefore southeasterly, while the upland Kansan on the Iowa side and on the South Dakota side south of Canton probably came from the northeast, and possibly at an earlier time within the Kansan period.

The Kansan plain.—The plain on the west side of the river has been referred to the Wisconsin because of its topography. The writer repeatedly traveled over various portions of this plain between the uplands south of Sioux Falls and those south of Canton and between Harrisburg and the river, and found that while the general surface of the plain is flat it is much more uneven than appears from a distance, and that its drainage is quite well developed along long draws, which culminate in such valleys as that of Spring Creek southeast of Shindlar and Beaver Creek southward. There are few entirely inclosed basins containing swamps and ponds, and the general character of the surface is very similar to that of the Kansan in O'Brien and Osceola counties in Iowa.

The plain slopes gradually to the southeast and east. The fall from

Harrisburg to Canton is 185 feet,[15] but the station at Canton is 30 feet or more below the general level of the plain near by.

As already noted, this plain is cut by valleys of varying depth, and these, together with road and railway cuts, reveal typical Kansan drift over all that part of it here discussed. A series of such exposures may be seen between Shindlar and the Big Sioux River along the Chicago, Rock Island and Pacific Railway; along the wagon road in section 35, township 100 north, range 49 west, and near the northwest corner of section 28 and the southeast corner of section 16 of the same township; near the northwest corner of section 18, township 99 north, range 48 west; near the northeast corner of section 20, township 99 north, range 48 west; near the northeast corner of the northwest quarter of section 29, township 99 north, range 48 west; south of the northwest corner of section 28, township 98 north, range 49 west, and elsewhere. Moreover, the bluff sections on the South Dakota side between Canton and Granite, which simply represent cut edges of the great plain, show typical Kansan drift plainly. The sections numbered 6, 10, and 11 are of this kind (number 10 being especially satisfactory), because they are not on the face of the bluff, wherewhere displacement might take place, but were cut directly into the strata of the plain, here somewhat elevated.

The Kansan drift of this plain is very calcareous and in other respects is like the drift of the uplands throughout this region, both weathered and unweathered phases appearing.

"The Altamont moraine."—As noted in the earlier part of this paper, the elevations south and southeast of Sioux Falls, the knobs near Canton, and the ridge extending southward from a point about 3 miles south of Canton have been regarded as a part of the Altamont moraine of the Wisconsin drift. The foregoing discussion brings out the fact that on these ridges there is no Wisconsin drift whatever.

The great ridge south of Canton, at least to the line extending west from Fairview, shows weathered Kansan drift at the surface northward and Kansan drift covered with two loesses southward. The whole mass is evidently of the same structure and origin as the great uplands on the Iowa side of the Big Sioux in Lyon County and southward and belongs with them.

The knobs northeast of Canton, particularly that in section 7, township 98 north, range 48 west, and that in section 20, township 99 north, range 48 west, are certainly Kansan, and are evidently also related to the uplands on the Iowa side.

---

[15]According to elevations in Gannett's Dictionary of Altitudes.

That part represented by Wilder as located in Lyon County, Iowa, consists either of terrace gravels or of ridges which are a part of the Kansan uplands on this side of the river, and differ in no important particular from corresponding formations in other parts of this region.

The ridge beginning west of Granite and extending northward toward Sioux Falls likewise shows only Kansan or loess at the surface, and this also is evidently related to the uplands on the Iowa side.

The conclusion naturally follows that the elevations heretofore specifically referred to the Altamont moraine are Kansan and belong with the Kansan area on the Iowa side.

The gravels of the river terraces.—The sands and gravels in the terraces along the Big Sioux River have been regarded as Wisconsin gravel trains.

The writer at first inclined to the opinion that they were Aftonian, but has come to the conclusion that they are Kansan. In at least one section, number 21, the bed of gravel rests on what appears to be Kansan drift, though the terrace sections in the vicinity of Granite show much irregularity in the arrangement of strata, and it is difficult to determine how much shifting and mixing has taken place. It is also noteworthy that these sands and gravels are not clean like most of the Aftonian, and no fossils have been found in them excepting the worn fragment of the molar of *Equus* in section 21, but this was probably derived from older strata, and, moreover, it was associated with a bone of much more modern appearance.

Perhaps the most satisfactory evidence that these gravels are Kansan is furnished in the vicinity of Sioux Falls. The high ridges and knobs lying to the northeast of Sioux Falls consist in large part of sand and gravel. The gravel in some cases forms the uppermost portions of the mounds or ridges, which are then covered by a very scant, stunted vegetation.

It is evident that these gravels are not older than the Kansan, for at a number of points typical Kansan may be clearly seen below them. That the gravels do not belong to a later drift, but are closely connected with the Kansan, is shown by the fact that at several points loess appears above them, and on at least one of these ridges two loesses, the lower gray and the upper yellow, overlie the drift and gravels. As previously noted, the gray loess always closely follows the Kansan drift and associated formations, and its presence here, capping a ridge more than 200 feet above the river, shows that the underlying materials are not younger than the Kansan.

Another fact is worthy of note: As has been pointed out, there are no

gravel terraces above Sioux Falls and none above the terrace island, which is only a short distance above these ridges of gravel, and this suggests that a great mass of gravel deposited by the Kansan in the rough area under discussion was the source of the gravels which largely make up the river terraces, and that the present knobs and ridges are a mere remnant of the original mass.

Additional plausibility is given to this conclusion by the fact that the terraces are highest immediately below and opposite these ridges and gradually decline as we go down the river. The following table of elevations, given in feet, shows this:

	I	II
Sioux Falls	1,397	80
Brandon	1,333 + 25	75
East Sioux Falls	1,323	45
Canton	1,246 + 4	27
Fairview	1,216 + 20	30
Hudson, South Dakota	1,224	..
Hawarden, Iowa	1,182	23
Chatsworth, Iowa	1,164	22

The first column contains the elevations above the sea of the tracks of the Chicago, Milwaukee and Saint Paul Railway at the several stations named as given by Gannett. At Sioux Falls the terrace is below the city, but at about the elevation of the Illinois Central depot. Brandon is about 25 feet lower than the terrace to the west. At Canton the terrace is not as distinct as it is across the river at Beloit, where it is about 4 feet higher than the Canton depot. At Fairview the terrace is 20 feet above the station, and at all the other points the depot is on the terrace level.

The second column represents the height of the terrace above the river at the respective points. It will be noticed that the altitude of the Hudson depot is greater than that of Fairview, and while the height of the terrace above the river was not determined it also seems to be greater. This is probably due to the accumulation of similar gravels which came down the valley of Rock River, which empties into the Big Sioux opposite Hudson.

South of Chatsworth the terraces become still less conspicuous and practically disappear before the Missouri Valley is reached.

Furthermore, the numerous upper benches, with their capping strata of gravel, and the strata of silt overlying the Kansan in Sioux Falls (see plate 10, figure 2), as far as observed practically at the same level, suggest that the waters of the Big Sioux below Sioux Falls had been dammed by the great gravel mass, thus raising the water level and making possible the deposition of sand and silt at what are now rather high

altitudes. The similar sand, gravel, and silt deposits which overlie the Kansan at East Sioux Falls may have been produced by overflow waters cutting across from the Sioux Falls lake to East Sioux Falls.

The facts here presented warrant the conclusion that the gravels of the terraces are related to the Kansan. They are not Wisconsin, for they can not be traced back to a Wisconsin source, and no Wisconsin was found in the area under discussion.

The loesses.—While very distinct, the two loesses do not attain great thickness, for they seldom reach a total depth of 10 feet in this region.

The small amount of loess is probably due to the absence of streams with broad beds and numerous bars, from which the wind could carry dust. Probably a large part of the upper or yellow loess was carried from the distant Missouri.

They cover the hills opposite Canton and northward, and also the uplands in the great bend of the Big Sioux both east and southwest of Sioux Falls and the uplands west of Fairview. Sometimes the lower loess is missing, and less frequently the upper is not present, but in the rougher areas both frequently appear in the same sections.

Fossils are very rare in the lcesses of this territory, possibly because the accumulation of the loess has been so slow that the shells disintegrated before they were completely buried. Mollusks now live in the region in timbered areas and have probably existed here for a long time.

Among the exposures showing two loesses the following may be mentioned:

On the north side of the northeast quarter of section 2, township 98 north, range 48 west, showing Kansan and both loesses.

On the north side of section 14, township 98 north, range 48 west, both loesses and Kansan appear in normal relative position.

Numerous sections appear along the road between the last section and the river, and other portions of the uplands east of Canton show similar sections.

In the southeast quarter of section 13, township 97 north, range 49 west, two loesses lying on Kansan drift are exposed in four sections on the south side and two on the east side of the quarter section, and several exposures along the road between this point and Fairview show the same formations.

Near the southeast corner of the southwest quarter of the southwest quarter of section 19, township 101 north, range 48 west, Kansan drift, bluish loess, and yellow loess appear in a cut along the road, and other portions of the uplands east of Sioux Falls show the same formations. It is evident that no Wisconsin drift occurs on these uplands.

Two loesses also appear southwest of Sioux Falls, as along the Chicago, Milwaukee and Saint Paul Railway, near the northwest corner of section 35, township 101 north, range 49 west, and in a road cut near the middle of the west line of section 33 in the same township.

The region south and southwest of Granite, Iowa, also shows a number of sections in which both loesses and sometimes Kansan drift appear. One of these exposures is near the southwest corner of section 19, in which Granite is located.

The bluish loess is typical post-Kansan loess of fine texture, bluish gray color, with frequent iron tubules, few rounded calcareous nodules, and in this region usually without fossils.

The yellow loess is looser in texture, coarser as a rule, with very numerous small irregular calcareous nodules in the uppermost 2 or 3 feet, and also almost without fossils.

The loesses are by no means uniformly distributed, for they are entirely lacking on many slopes, and even on the summits of knobs and ridges.

Conclusions

The more important conclusions derived from the observations herein briefly recorded are as follows:

1. The ridges southwest, east, and southeast of Sioux Falls and south of Canton are not a part of the Altamont moraine, but are Kansan.
2. The plain extending from Shindlar to Canton, South Dakota, is Kansan and not Wisconsin.
3. The gravel terraces along the Big Sioux are not Wisconsin gravel trains, but are probably Kansan.
4. The interglacial silt at Sioux Falls is of Aftonian origin, but has been disturbed by the Kansan.
5. There is no Wisconsin drift in the western part of Lyon County, Iowa.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

SYMPOSIUM ON TEN YEARS' PROGRESS IN VERTEBRATE PALEONTOLOGY[1]

R. S. BASSLER, *Secretary*

(*Held by the Society December 29, 1911*)

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INTRODUCTION

For the third annual meeting of the Paleontological Society, held at Washington, it was suggested by several members of the Council that a portion of one day might well be devoted to a Symposium on Ten Years' Progress in Vertebrate Paleontology. This was approved by the remaining members, and the Secretary was instructed to arrange such a symposium, following an outline which had been submitted by Vice-President W. D. Matthew. As the time limit on these papers had necessarily to be

[1] Received by the Secretary of the Geological Society of America January 31, 1912.

short, little detail could be given, but in order that certain phases of the subject be discussed it was suggested that each participant include, if possible, remarks on the following points:

(*a*) Status of our actual knowledge and principal material in different museums which has been brought together in rec

(*b*) Theories accepted and rejected in recent years.

(*c*) Hypotheses on trial.

(*d*) Important investigations and explorations which sh

AFRICAN MAMMALS

BY W. D. MATTHEW

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Location and Elements of the Fayûm Fauna

The discovery of the Fayûm fauna is the most important find of the last decade in vertebrate paleontology. It has added a new and most remarkable type of giant quadruped, primitive stages in the evolution of the Proboscidea, Sirenia, and Cetacea, a wide variety of Hyracoidea, besides Carnivora, Rodents, and, if Doctor Schlosser is correct, the earliest known Anthropoid Primates.

The principal fauna is found in the Fluvio-marine beds of the Fayûm district in Egypt, regarded as Upper Eocene by the Egyptian Geological Survey, but now generally accepted as Oligocene from the evidence of the marine invertebrate fauna in the underlying horizon. The marine mammals and a few land mammals of doubtful affinities are found in the underlying marine formation, unquestionably of Eocene age.

The Fayûm fauna consists of three elements:

1. Terrestrial mammals nearly related to the Upper Eocene and Oligocene fauna of Europe and North America, and whose ancestors are found in the Eocene of these countries.

2. Terrestrial mammals not related to the above, except through common derivation from the primitive Paleocene placentals, representing

groups whose ancestors are not found in the Eocene of Europe and North America.

3. Marine mammals related to Eocene and Oligocene Cetaceans and Sirenians of Europe and North America, but in some cases more primitive.

The first group must be regarded as recent immigrants from the northern continents. The second group may be provisionally regarded as autochthonic, evolved in Africa during the Eocene. We can not be certain that they were so because we know next to nothing of the early Tertiary mammals of any part of Asia. But there are good grounds for the inference that they were not evolved in northern or north-central Asia nor in Europe, North America or South America nor Australia. The third group is presumably Mediterranean, but the presence of primitive survivals indicates perhaps that the North African coast was *not* the center of dispersal of these animals.

Arranging the fauna thus, we have:

IMMIGRANTS	AUTOCHTHONES	MARINE
1. Carnivora (Hyænodonts)	1. Embrithopoda	1. Sirenia
Hyænodon	*Arsinoitherium*	*Eotherium*
Pterodon	2. Proboscidea	*Eosiren*
Apterodon	*Palæomastodon*	*Protosiren*
Metasinopa	? *Mœritherium*	2. Cetacea
2. Rodentia (Theridomyids)	? *Barytherium*	*Eocetus*
Phiomys	3. Hyracoidea	*Protocetus*
Metaphiomys	*Megalohyrax*	*Zeuglodon*
3. Artiodactyla (Anthracothores)	*Saghatherium*	
Ancodon	*Geniohyus*	
Rhagatherium	*Bunohyrax*	
	Mixtohyrax	
	Pachyhyrax	
	4. ? Insectivora	
	Ptolemaia	
	Metolbodotes	
	5. Primates	
	Parapithecus	
	Propliopithecus	
	? *Apidium*	

More than half these genera are represented by well preserved skulls; a few by a large series of skulls of several species. Great series of vertebræ, limb and foot bones have been collected, but except for the marine genera there is practically no association of skull and skeleton parts, and the identification of the bones is based on considerations of size, zoological affinities, and relative abundance of the different bones and consequently

is inexact or doubtful in most cases. The vertebræ, limb and foot bones of *Arsinoitherium*, vertebræ and limb bones of *Mœritherium*, *Palæomastodon*, and *Ancodon*, limb bones of *Apterodon* and *Pterodon* have been identified with reasonable certainty. The remaining land mammals are known only from skulls and jaws (except *Barytherium*, jaws and parts of limbs).

The results so far obtained are due in the first place to the work of the Egyptian Geological Survey and the British Museum; the American Museum of Natural History and the Stuttgart Museum have since secured fine collections. The earlier collections were described by Doctor Andrews in 1906; the Stuttgart and American Museum collections have not yet been fully described, but are partly known from preliminary notices.

In considering the affinities of this fauna it is well to remember that Egypt is today zoologically a part of the Holarctic, not of the Ethiopian region. Its fauna includes a minority of Ethiopian genera, but is mostly related to that of southern Europe and western Asia. But in the early Tertiary the eastward extension of the Mediterranean separated Africa more or less completely from the northern world, while the Saharan desert was probably not an eeffctive barrier as it is today. Egypt was then part of an isolated Ethiopic continent, with possible Asiatic but no European connection during the early Tertiary. So much is certain from the known extent of marine formations of that period.

Immigrant Group

Reviewing the fauna more in detail, the immigrant group includes three orders of mammals, each represented by one family. The Carnivora all belong to the Creodont family Hyænodontidæ. No modernized (Fissipede) carnivora are present, although these had already appeared in the European and North American Upper Eocene. The Hyænodont genera are all Holarctic except one, which has not been found in the north, although perhaps merely from lack of evidence. But the species are very distinct, and unfamiliar in adaptive type; one would conclude that the Hyænodonts, invading a new field where they were not in competition with other families of carnivora, were expanding and modifying into new adaptations.

The Artiodactyla include also but one family, the Anthracotheres, and of these only one common genus, *Ancodon*, with two or three species, allied to Upper Eocene and especially to early Oligocene species of Europe. This genus is not found in North America until the Lower Oligocene.

The rodents are scarce, and referable to the European Theridomyidæ, a group intermediate between the Hystricomorph rodents and the primitive rodents of the early Eocene. This group is known only from Europe, and was probably evolved in the Palæarctic; the Fayûm genera are imperfectly known, but compare with those of the late Eocene and early Oligocene in France and Germany.

The most remarkable feature about the immigrant mammals is their limitation. The Perissodactyla, the most abundant mammals in the northern Eocene, are entirely absent. This can hardly be a matter of accident. Some barrier there must have been, whether of range or habitat, which prevented any of the Lophiodonts, Hyracotheres, and Palæotheres from accompanying the Hyænodonts and Ancodons with which they are found in Europe. The absence of Fissipede, or true Carnivora; of Anoplotheres, Xiphodonts, Dichobunids, Cænotheres, and other families of Artiodactyls, and of other rarer mammals of the European Upper Eocene may be in some cases a matter of accident; in others significant.

Autochthonic Group

The most remarkable of the autochthonic group is the *Arsinoitherium,* a gigantic quadruped with elephantine limbs and a pair of great horns at the front of the skull. It is the sole representative of its order, and, except for distant and disputed affinities to the Hyracoids, has no known relatives. It is analogous to the *Uintotherium* of North America, but most authorities concur in attributing the resemblances to adaptive analogy, and conclude that the *Arsinoitherium* evolved out of some primitive Hyracoid stock in Ethiopia during the Eocene, while the Uintatheres were evolving in North America out of the primitive Taligrade stock.

The supposed ancestors of the Proboscidea, *Mœritherium* and *Palæomastodon*, are of especial interest. There is no doubt about the position of *Palæomastodon.* It is Proboscidean beyond question; decidedly more primitive than any known Holarctic Proboscidea, as well as an entire epoch earlier in point of time, and, so far as appears, is in the direct line of descent. The position of *Mœritherium* is not so certain. It is found both in the Upper Eocene and Lower Oligocene horizons, and is generally regarded as an earlier stage of specialization of the Proboscidea, ancestral to *Palæomastodon*, but surviving along with it. Osborn, however, regards it as open to serious question whether *Mœritherium* can be regarded as at all directly ancestral to *Palæomastodon.*

The conclusion has been generally drawn that the Proboscidea evolved in the Ethiopian region. This conclusion, however justified by the evi-

dence as it stands, is not in accord with the later distributional relations of this order as the present writer sees them. What we know of the modern and Pleistocene and later Tertiary distribution of different species of Proboscidea seems to point to an Asiatic, not Ethiopian, center of dispersal for this order since the Miocene. It is, of course, possible that the Proboscidea reversed the normal course of migration and dispersal and were at first Ethiopian, then Asiatic. But we have hitherto known nothing of the Oligocene fauna of Asia, and until we know the results of Pilgrim's and Cooper's explorations in the Oligocene of Baluchistan it may be well not to regard the African origin of the Proboscidea as a settled question.

The third autochthonic group, Hyracoidea, had been known only by the two closely related surviving genera, *Procavia* and *Dendrohyrax,* limited to Africa and Syria, and without known fossil relatives except the *Pliohyrax* of the late Tertiary of Samos and Pikerni. In the Fayûm fauna Hyracoids are abundant, small or medium sized, some bunodont, others bunolophodont. It is generally accepted that they took the place in the Ethiopian early Tertiary fauna of the missing Perissodactyls and Artiodactyls, as the Notoungulata did in the Tertiary of South America.

Marine Group

The Sirenians and Cetaceans are chiefly from the marine Mokattam and Quasr-es-Sagha beds, late Eocene in age. The Sirenian genera, *Eotherium, Eosiren,* and *Protosiren,* show a very marked approach in the structure of skull, teeth, and certain parts of the skeleton to the early Proboscideans, especially *Mœritherium,* and leave little doubt of the derivation of Proboscidea and Sirenia from a common early Eocene ancestor. The Cetacea include besides *Zeuglodon,* already known from the European and North American Upper Eocene, other more primitive genera, *Eocetus* and *Protocetus,* which show a marked approach toward the Creodonta and certain special points of resemblance to *Hyænodon.* The latter, Matthew has shown, must be ascribed to convergence, and the former are more probably resemblances to the common primitive Creodont-Insectivore stock than to the Creodonts in particular. There are equally marked points of resemblance to certain of the Eocene Insectivora.

Insectivores and Primates

Two scarce and little known genera, *Metolbodotes* and *Ptolemaia,* have been provisionally referred to the Insectivora. The former is said by

Schlosser to be related to the Mixodectidæ of the basal Eocene of North America; the latter is referred by the same author to the Hyænodonts.

The most interesting group among the smaller mammals is the Primates. Two genera have been described by Schlosser from well preserved jaws and referred to the Anthropoidea. If so they are much the oldest Anthropoidea known, for all the numerous Eocene and Oligocene Primates of Europe and North America are either certainly or probably Lemuroidea, and although some of them may have been ancestral to Anthropoidea they had not progressed to the monkey stage of evolution. So far as the teeth are concerned, these Fayûm Primates are distinctly anthropoid. It should be remembered, however, that the Archæopithecidæ, Lemuroids of Pleistocene Madagascar, paralleled the true Anthropoidea in teeth and several features of the skull. Schlosser's reference of one of the genera, *Propliopithicus,* to the Simiidæ, and reference to it as the direct ancestor of man, was criticized by Matthew as not warranted by the evidence presented in favor of a conclusion so profoundly important.

Explorations in the Pleistocene swamp deposits of Madagascar have been continued with great success, and the British Museum, Paris Museum, and Vienna Museum have secured splendid series of skulls and skeletons of the extinct *Megaladapis* and other Lemuroid genera. These have been thoroughly studied and monographed by Forsyth Major, Standing, Grandidier, and Lorenz von Liburnau. Grandidier concludes that these genera are closely related to the European Oligocene genus *Adapis,* and that the Lemuroids form an order distinct from the Anthropoids. Standing regards them as being closely related to the modern Lemuroids, but having little to do with the Adapidæ, while he does not admit the separation of Lemuroidea and Anthropoidea even as distinct suborders. A careful study of the Eocene Primates of North America and Europe, with the complete skulls and skeletons now at hand, will probably furnish the key to the true affinities of these Malagasy Primates.

Some of these Malagasy giant Lemuroids may have survived until quite recent times. Trouessart[2] quotes a passage from an early description of Madagascar (Flacourt, 1658), which might refer to one of the short-faced genera like *Archæolemur:* "The Tratratratra is an animal as large as a heifer, with round head and the face of a man; the fore feet are like those of a monkey and so are the hind feet. The hair is frizzled, the tail short, and the ears like those of a man. It is seen near the Strait of Lipomani, in which neighborhood are its haunts. It is a solitary animal; the people of the vicinity are much afraid of it and flee from it, as it does from them."

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[2] Rev. Crit. Palæozool., vol. ix, p. 176.

These are the chief additions to our knowledge of African fossil mammals of the last decade of mammalian paleontology. There are a few scattered records in North Africa and South Africa of fragmentary Pleistocene fossils, somewhat archaic in aspect and suggestive of the late Pliocene fauna of Europe. Far more important than these is the recent discovery of remains of Tertiary mammals in central Africa on the east side of the Victoria Nyanza. The first fragments found were reported by Doctor Andrews to include *Dinotherium*, a small rhinoceros, and several other genera, and the locality is now being investigated by an expedition from the British Museum.

Conclusions

The general conclusions warranted by the above discoveries are:

(1) Africa during the Eocene was an isolated continent like Tertiary South America, and like Australia still is. It developed a peculiar mammalian fauna from primitive placental ancestors, which must have reached it about the end of the Cretaceous. This fauna included the Arsinoitheres and Hyracoids, and more doubtfully the Proboscideans. (2) The autochthonic fauna was overwhelmed during the Oligocene by invaders from the north, and has left only a few survivors (*Hyrax*, perhaps *Elephas*). The recent discoveries in central Africa may perhaps solve the question whether the European invaders had completely supplanted the authochthonous fauna in the Miocene; but in Pleistocene and modern Africa only one or two traces are left. (3) The mammalian fauna of Madagascar does not appear in the light of present knowledge to be a survival of an early Tertiary African fauna, but rather a composite fauna, disharmonic, like that of oceanic islands, originating not from one or several faunal invasions, but several arrivals of single genera at different times.

ARTIODACTYLA

BY O. A. PETERSON

The present status of work in Vertebrate Paleontology in connection with the suborder Artiodactyla during the past decade is a broad subject which I can not claim the ability to treat here with full justice, although the Council of our Society assigned the work to me. I can not enter into details and will only touch on a few points which to me appear of most importance and prominence, while appended hereto is a bibliography with especial reference to proposed families, genera, species, and subspecies for the past ten or twelve years.

To begin with, I wish to refer to the splendid collections, especially of the Artiodactyla, from the Uinta Eocene of Utah, brought together by the American Museum of Natural History and Princeton University. This carries us further back than ten years (1895-1899), but it is within the scope of this paper, since the material in question opens up a vista of much importance in connection with paleontology. It is from this Upper Eocene horizon that we get the first glimpse of the true selenodont Artiodactyla in North America, so ably presented in publications (Scott, 1899) by the eminent and worthy President of our Society and by Dr. J. L. Wortman (1898). The fauna of the succeeding Tertiary formation (Oligocene), which had previous to these years been comparatively well known, was now carried back a great step in geologic time, and speculations as to the origin of still earlier representatives of these North American Artiodactyls naturally arose.

From this time on to the present a rapid succession of field explorations, especially in the United States, was carried on in the years 1898-1901 by the American Museum of Natural History, Princeton University, and other institutions. In later years these institutions were joined in the field by Amherst, Carnegie Museum, Field Museum, Yale, and a number of western institutions. Thus activity in our work has been on a constant increase, and our knowledge has rapidly advanced from the united labors of the different institutions in America and abroad.

Though perhaps not bearing directly on the subject in hand, the monumental and epochal work done at Princeton on the Santa Cruz fauna from Patagonia furnishes food for some thought. In this vast collection of fossils, including those gathered from time to time previously, there is no sign of a true Artiodactyl or Perissodactyl. On the other hand, we see the very remote ancestral relationship, for instance, between the Artiodactyla and Perissodactyla of the north and the Litopterna of the Santa Cruz beds. It is also more solidly established (Scott, 1910, pages 105-154) than before that *Macrauchenia* from the Pampean can no longer be referred to the Tylopoda, as was originally done.

In speaking of the recent paleontological discoveries in Africa, it must be a considerable satisfaction to such men as Professors Osborn (1900, pages 56-59), Stehlin (1900, pages 478-488), and Tullberg (1899, pages 485-495) to have their prophecies come to at least a partial realization so soon after their studies (I refer to their arguments of an African home in early geologic times for the various families discussed). Through the energies of Schweinfurth and Dames, the original workers in this field, and later through Beadnell, of the Geological Survey of Egypt; Andrews, of the British Museum; Fraas, of Stuttgart; Schlosser, of Munich; Os-

born and his staff of the American Museum, as well as many others, we have now come to realize from the studies by these men of the material gathered that Africa was an important dispersing center in early Tertiary times, the phylogenies of Simiidæ. Insectivora, Creodontia, Rodentia, Proboscidia, Sirenia, Zeuglodentia, and Hyracoidea being especially significant. The earlier ideas that Africa was invaded by the primitive stock which originally came from the north, and that the country afterward received waves of new and more highly specialized forms from the same direction, will apparently have to give way to a great extent because of the recent knowledge obtained.

While the suborder Artiodactyla is not as yet well represented in the known fossil fauna of Egypt, we do find, in Doctor Andrew's Descriptive Catalogue (1906), such genera of the Upper Eocene as *Ancodon* and *Rhagatherium* of the Anthracotheriidæ.

Geniohyus was included in the Suidæ by Andrews, but Schlosser has very recently[1] placed this so-called suid with the Hyracoidea (*Bunohyrax* n. g.). The true ancestral forms of later Tertiary anthracotheres, or pigs,[2] not being recognized either in the European or American Eocene, we may ask: Did they come from a North-Asiatic center, or is it possible that they originated in Africa? Schlosser's recent work (loc. cit.) appears to be negatory to the latter idea, but may we not yet find in the Tertiary deposits of Africa not only the remains of the Hippopotamidæ and anthracotheres, but possibly even the representatives of the Suidæ and, shall I say, the antelopes? Is it possible that we may yet find the ancestors in the African Tertiary[3] of the great ruminant fauna which at present occupies that country?

Our interest in connection with the Artiodactyla was more especially directed toward the survey of the earlier ancestors of the Agriochœridæ, the Tylopoda, and the Tragulina, while in the last few years the pendulum swung in the other direction and the entertainment—that is, the effort to keep up with the results and progress from the collections gathered in the later Tertiary deposits, especially of the United States—is equally interesting. Of the many institutions which have recently contributed to our knowledge of the Artiodactyla, the American Museum of Natural History has been especially active in acquiring material and of study. Much work has been done by the California, Amherst, Yale, and Princeton Universities, the State universities of Nebraska, Kansas,

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[1] Max Schlosser: Beiträge zur Paläontologie und Geologie Osterich-Ungarns und des Orients. Band xxiv, 1911, pp. 118-124.

[2] See Stehlin's discussion on the pigs and anthracotheres of Europe.

[3] Livingstone in his "Missionary Travels and Researches in South Africa," chapter 26, p. 556, speaks of fossil bones which lie in the calcareous tufa of the region he traversed.

Wyoming, the National, the Carnegie, the Field museums, as well as other institutions. Even private parties have been interested.

This material collectively has furnished data which are far-reaching, not only in paleontology, but in geology as well. Time and place do not here permit of geologic discussion. However, in passing it is well to mention that we have in the last few years happily emerged from the idea of the supposed vast Tertiary inland lake, covering many States east of the Rocky Mountains, to a much more reasonable supposition of actual dry land, with smaller lakes, rivers, and forests which covered this same Mississippi-Missourian area during the later Tertiary time. The comparatively recent activities of such men as Davis, Fraas, Gilbert, Hatcher, Haworth, Matthew, Merriam, Williston, and others originally brought about this change from field observations and from the study of the faunæ obtained. The proposed phylogenies of the Artiodactyla from recent material collected have taken a considerable forward step, so that if equal activities continue in the future it would appear that our text books on geology and paleontology will have to be revised more often than heretofore.

Through systematic work in western Nebraska and eastern Wyoming by the Carnegie Museum in 1900-1902 a certain series of sediments were brought to considerable prominence (Hatcher, 1902), and in succeeding years a number of other institutions were engaged in the same general field. The Lower Miocene had long been wanting in the Tertiary strata of our country, and the fauna of these beds is regarded as of very late Oligocene or Lower Miocene Age. The Monroe Creek and lower Harrison beds are especially looked on as Lower Miocene, while the upper Harrison beds may be regarded as the base of the Middle Miocene. A rich vertebrate fauna has been recovered from these sediments, which have assisted much in recent phylogenetic studies.

Dr. W. D. Matthew (1908) and Mr. Earl Douglass (1909) in some of their work devoted to the Artiodactyla have finally relieved us of the perplexity of grouping certain American Miocene genera (*Merycodus, Blastomeryx,* and *Dromomeryx*) with contemporaneous European genera (*Paleomeryx, Dicrocerus, Amphitragulus, Dromotherium*).

The small deerlike form *Merycodus* from the American Miocene and *Capromeryx* (Matthew, 1902, page 318) from the Pleistocene are placed in a new family (*Merycodontidæ*, Matthew, 1904) with equal rank as the Antilocapridæ, the Cervidæ, the Bovidæ, etcetera, while the new genus *Dromomeryx* (*Palæomeryx*) Douglass is placed in the cervids under the subfamily Palæomerycinæ. Matthew would separate the European cervids from those of the New World and has worked out a phyletic series

of the American Cervidæ. The Oligocene genus *Leptomeryx* is regarded as of primitive unspecialized peccoran stock, which accordingly precludes a direct ancestorship to the Cervidæ as a whole, because the American genus is contemporary with more advanced peccoran forms of the Old World. On the other hand, the Oligocene genus of America is regarded as in line with *Blastomeryx* from the Miocene of the same general region. The latter genus is in turn placed in the line of the recent American deer (*Mazama* and *Odocoileus*). If we carry the line from *Leptomeryx* back a step to the Eocene form *Camelomeryx* (Scott, 1899, pages 67-73), or some other contemporaneous genus, we would have the cervids practically as complete as any known phyletic series of the mammalia.

Much material of the characteristic North American family Agriochœridæ has been accumulated the past ten years. The American Museum of Natural History and the Carnegie Museum especially have been active in securing material of this family. No less than eight genera, forty or more new species and subspecies, have been proposed (see Douglass, Matthew, and Peterson), which further indicate the great variety of forms when the large number already established is considered. That this great branch of the American Tertiary artiodactyls was, during its existence, capable of acquiring a variety of characters, which in some respects are equal to or even greater than those of the Tylopoda or any other branch of the Artiodactyla is evident, but why we should have no recent representatives, while the tylopods, the deer, and the peccaries survived, is in reality as yet little understood, though we do hold the opinion that one of the chief causes of their extinction is due to inadaptive combinations of characters. The family Agriochœridæ is very much in need of a revision.

Material of the fossil camels has been assembled in recent years, which has resulted in a number of taxonomic changes of this important family. As facts accumulate we are obliged to trim the phyletic trees and sometimes we meet with surprises entirely unlooked for. Among the more recent surprises in this connection are perhaps the new genera *Eotylopus reedi* (Matthew, 1910) from the Lower Oligocene of Wyoming and *Stenomylus* (Peterson, 1906-1908) from the Lower Miocene of western Nebraska. The former genus is regarded as a primitive ancestor of the Camelidæ, found together with *Pœbrotherium*, a much more advanced type, generally looked on as in the line to the recent camels, while the latter is highly specialized in the dentition and many other features of the cranium, plainly indicating a third line of early Tertiary origin (Upper Eocene). The Stenomylins are already well known, there being approximately one hundred or more individuals found, many of which

are complete skeletons (see Loomis and Peterson). The Giraffe-camels, *Alticamelus* from the later Miocene (Matthew, 1901, page 429), is a fourth branch, which is traced to the Upper Oligocene through the Lower Miocene genus *Oxydactylus* (Peterson, 1904). These forms, with the exception of *Pœbrotherium,* are all aberrant types. As in the Agriochœridæ, the fossil camels stand much in need of a thorough revision. Other Artiodactyls, such as *Syndyoceras* (Barbour, 1905, page 797) and *Dinohyus* (Peterson, 1905, pages 211-212, 719), are of especial interest. The former is placed in the descending line of the subfamily Protoceratinæ, carrying this curious Oligocene family one step further forward in geologic times, while the latter genus belongs in the Entelodontidæ, and the completeness of the material in the Carnegie Museum formed the basis of a revision of that family (Peterson, 1909). Material of the Miocene peccaries of North America has recently been found and described (Peterson, 1906; Matthew, 1907; Loomis, 1910), and Dr. Loomis has concluded that the Oligocene immigrant from Asia to America represents, in the Pleistocene, three lines, *Platygonus*, *Mylohyus*, and *Tayassu* (loc. cit., page 384), the latter genus only continued to the present time.

A most surprising discovery was made during the last few years by Drs. W. D. Matthew and J. C. Merriam. Matthew and Cook (1909, pages 361-414) report, for the first time in North America, a true antelope (*Neotragocerus*, loc. cit., page 413) from the Pliocene of western Nebraska, which appears to be, according to Matthew and Cook, related to the tragoceran group of European Miocene, while Merriam contributes papers on fossil antelopes (*Ilingoceras* and *Sphenophalos,* 1909, pages 319-330) of the twisted horn type from the Tertiary in Virgin Valley and on Thousand Creek of Nevada, which have affinities to the tragelaphines found in the Siwaliks of Asia, the nilgau, kudu, and other recent African antelopes. It is also pointed out that these Nevadan antelopes, especially *Sphenophalos*, resemble the existing American prong-horn antelope, and from Merriam's three hypotheses (1911, page 302, (1) that they are Miocene or early Pliocene immigrants from Europe; (2) that they have tragelaphine forms, which originated from Merycodus-like American ancestors some time during the Miocene, immigrated to the Old World, and only having a few descendants here until late Miocene, or (3) that they are a peculiar twisted-horn division of the Antilocapridæ originating in America and possibly limited to this continent) it would seem that an American origin for these Miocene and Pliocene remains is most strongly favored, *Ilingoceras* being tentatively placed in a distinct family (Ilingoceridæ), while *Sphenophalus* is placed in the Antilocapridæ (loc. cit., page 303).

Among the interesting features in connection with the American Pleistocene is the work now going on in the famous La Brea asphaltum deposits of southern California (Merriam, 1908; Gilbert, 1910). Much exploration and work have also been done by Merriam, Mercer, Sinclair, Furlong, and others in caves and other deposits on the Pacific coast. The bone deposits of the Conard fissure in northern Arkansas have been studied by Mr. Barnum Brown (1908). A preliminary paper was contributed by Dr. W. J. Holland on the collection from the Frankstown Cave in Pennsylvania (1908). The Aftonian deposit of mammalian remains in Iowa is a recent discovery of much importance geologically (Calvin, 1909). Much work has recently been done in Alaska by the National (Gilmore, 1908) and American Museums (Quackenbush, 1909). A great number of other discoveries of comparatively recent date have been made by other institutions. This material, collectively, has furnished a new and powerful impetus in the extremely interesting and intricate study of the Pleistocene. The testimonies, though sometimes of fragmentary character, furnish ideas of great geographic range and zoologic diversity, not only of the Artiodactyla, but of the mammalia as a whole. Especially important is the manner in which the mammalian remains have assisted, as time-markers, in recent studies of glacial and interglacial periods (Calvin, 1909, page 137). Recent discoveries of fossil mammalian remains in Cuba and in Mexico give great promise and may direct some energies into Central and South America in the near future. But the more important fields in connection with Artiodactyla, as well as mammalia in general, are undoubtedly in Asia, especially the northern parts, and in Africa.

Finally, we come to the capstone of the monument of the ten years' progress, Osborn's "Age of Mammals," a masterly treatise, giving most useful information in connection with mammalian paleontology, quite indispensable to the worker in that field.

Principal Literature with Reference to New Families, Genera, Species, and Subspecies of Fossil Artiodactyla of the Past Ten Years

De-Alessandri, Giulio:

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Andrews, Charles W.:

1899. "Fossil mammalia from Egypt." Geological Magazine, n. s. (4), vol. vi, 1899, pages 48-484. [*Brachyodus africanus* n. sp.] Also vol. 1, 1904. [Page 160, *Geniohyus mirus* n. g. page 162, *G. fayumensis* n. sp.; page 212, *G. mayor* n. sp.]

Andrews, Charles W., and Beadnell, H. G. L.:
1902. "Preliminary note on a new mammal from the Eocene of Egypt." Cairo Survey Department, 1902, page 7. [*Ancodon* (*Ancodus*) *gorringei* n. sp.]
1906. "Descriptive catalogue of the Tertiary vertebrata of the Fayum, Egypt," 1906, British Museum, London. [Page 189, *Ancodon parvus* n. sp.; page 192, *Rhagatherium ægyptacum* n. sp.; pages 193-196, *Geniohyus*.]

Barbour, Erwin H.:
1905. "A new Miocene Artiodactyl." Science, n. s., vol. xxii, 1905, pages 797-798. [*Syndyoceras cooki* n. g.] Also "Notice of a new fossil mammal from Sioux County, Nebraska." Nebraska Geological Survey, vol. ii, 1905. [*Syndyoceras cooki*.]

Bate, Dorothea M. A.:
1909. "Preliminary note on a new Artiodactyla from Majorca." Geological Magazine, n. s. (5), vol. vi, 1909, pages 385-388. [*Myotragus balearicus* n. g.]

Broom, R.:
1909. "On a large extinct species of Bubalis." Annals of the South African Museum, vol. vii, 1909. [Page 280, *Bubalis priscus* n. sp.]

Brown, Barnum:
1908. "The Conard fissure, a Pleistocene bone deposit in northern Arkansas, with descriptions of two new genera and twenty new species of mammals." Memoirs of the American Museum of Natural History, vol. ix, 1908, pages 155-208. [Pages 200-205, Artiodactyla; page 203, *Symbos australis* n. sp.]

Calvin, Samuel:
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Cook, Harold J.:
1909. "Notice of a new camel from the lower Miocene of Nebraska." American Naturalist, vol. xliii, 1909, pages 188-189. [*Oxydactylus campestrus* n. sp.]

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1900. "Goat antelope from the cave fauna of Pikes Peak region." Bulletin of the Geological Society of America, vol. 11, 1900, pages 610-612. [*Nemorhœdus palmeri* n. sp.]

Depéret, Charles:
1906. "Los Vertebrados del Oligocene Inferior de Tarrega (Prov. de Lérida)." Barcelona Mem. R. Ac. Cs., ser. 3, vol. v. [Page 402, *Brachyodus cluai* n. sp.]
1908. "L'histoire géologique et la phylogénie des Anthracotheridés." C. R. Acad. Sci., Paris, T. 146, 1908, pages 158-162. [*Lophiobunodon* n. g., 2 n. sp.; *Microbunodon* (*Anthracotherium*) *laharpei; Microselenodon* (*A.*) *minimum; Amphirhagatherium* (*Rhagatherium*) *fronstettense; Calodontherium* (*Calodus*) *rutimeyeri*.]

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1901. "Fossil mammalia of the White River beds of Montana." Transactions of the American Philosophical Society, vol. xx, 1901, pages 237-279. [Page 256, Artiodactyla; *Bathygenus alpha* n. g.; page 259, *Lemmenetes platyceps* n. g.; page 262, *L. anceps* n. sp.; page 265, *Eucrotaphus helenæ* n. sp.; page 267, *Agriochœrus maximus* n. sp.; page 268, *A. minimus* n. sp.; page 269, *Arretotherium acrideus* n. g.]

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1907. "Merycochœrus and a new genus of Merycoidodonts, with some notes on other Agriochœridæ." Annals of the Carnegie Museum, vol. iv, 1907, pages 84-109. [Page 94, *Pronomotherium* (*Merycochœrus*) *laticeps;* page 99, *Eucrotaphus dickinsonensis* n. sp.; page 100, *E. montanus* n. sp.; *Merycoides cursor* n. g.; page 102, *Mesoreodon* (?) *latidens* n. sp.; page 104, *Promerycochœrus hatcheri* n. sp.; *P. grandis* n. sp.; page 106, *P. hollandi* n. sp.; page 107, *Ticoleptus breviceps* n. sp.; page 108, *T. bannackensis* n. sp.]

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400-406, Artiodactyla; pages 467-468, Diagrams of genetic relations of the orders.]

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1909. "Säugetierreste aus einigen Braunkohlenablagerungen Bosniens und der Herzewina." Saragevo Wiss. Mitt. Bosn. Herceg., vol. xi. [Page 558, *Dorcatherium* (*Hyœmoschus*) *rogeri* n. sp.]

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Revision of Boöidea; page 103, Merycoidontidæ n. fam.; page 107, *Merycodus osborni* n. sp.; page 125, *Blastomeryx wellsi* n. sp.] Also "Notice of two new Oligocene camels." [Page 211, *Pseudolabis dakotensis* n. g.; *Miolabis* (*Paratylopus*) *primævus* n. subgen. and n. sp.]

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1908. "Osteology of Blastomeryx and phylogeny of the American Cervidæ." Bulletin of the American Museum of Natural History, vol. xxvii, pages 535-562. [Page 543, *Blastomeryx primus* and *B. olcotti* n. sp.]

1909. "Observations upon the genus Ancodon"? Bulletin of the American Museum of Natural History, vol. xxvi. [Pages 1-7, *Ancodon* (?) *Bothriodon leptodus* n. sp.; page 6, discussion of synonomy.]

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PERISSODACTYLA

BY J. W. GIDLEY

Due to modern expert methods of collecting, the past few years have added very greatly to the collections in our various museums, both in number and quality of specimens representing the Perissodactyla. The various field parties sent out by the American Museum of Natural History have been very fortunate in bringing together many skeletons and good skull material, especially of the horses, rhinoceroses, and Titanotheres. Other expeditions, especially those of the Carnegie Museum, the University of Nebraska, and Amherst University, have also added many new and valuable specimens to the general store. The study of this better material, together with the revision of the old, by Osborn, Matthew, Gidley, Granger, and others, has marked a very considerable advance in our knowledge of the Perissodactyla.

Notwithstanding the good results reached through recent extensive studies, aided by this new and more complete material collected in recent years, the classification of the order is still in an unsettled state and many other problems await the discovery of more and better material to work out their solution. Thus it is not possible as yet to give an altogether satisfactory classification, or even to define the families and subfamilies in such a way that some objection would not be made by one authority or another. Osborn in his latest classification[1] divides the order into four superfamilies and eight families, as follows:

I. Titanotherioidea, including two families, the *Palæosyopidæ* and *Titanotheriidæ* (all extinct).
II. Hippoidea, including the two families *Equidæ* and *Paleotheriidæ.*
III. Tapiroidea, including the two families *Tapiridæ* and *Lophiodontidæ.*
IV. Rhinocerotoidea, including the two families *Hyracodontidæ* and *Rhinocerotidæ.*

Under these 8 families, 74 genera are included. Up to the present time about 500 species of Perissodactyls, living and extinct, have been recognized. Of these about 475 are extinct, and future explorations in the fossil fields will doubtless add many more to this number. Thus it seems evident that the order has long since reached its zenith of development and is now on the rapid decline. The extinction of the Titanotheres seems to have been accomplished before the close of the Oligocene, but

[1] The Age of Mammals, 1910, p. 555.

the other three superfamilies are represented today by a single family each. The living species in their present natural habitat, with the exception of the American Tapirs, are all confined to the Old World, a fact the more interesting in that North America seems to have been the birthplace or at least the stage for the development, not only of the early representatives of all the living Perissodactyls, but of most of the extinct groups of the order as well. More than half the total number of Perissodactyl species described have been founded on specimens from the Tertiary and Quartenary formations of this country.

The earlier theories held by Cope, Osborn, Schlosser, and others respecting the ancestry of the Perissodactyla and the relationship of this order, as well as that of the Artiodactyls to the Condylarths, have been for the most part abandoned, and on very good ground. Matthew,[2] in his revision of the Puerco-Terrejon fauna in 1897, pointed out in *Euprotogonia,* a formerly proposed ancestor of the Perissodactyla, certain characters of foot structure, which, while denoting a position for this genus ancestral to *Phenacodus* of the Wasatch, showed conclusively that it could not be regarded in any way ancestral to the Wasatch Perissodactyls. No later discoveries have thrown any real light on the early development of this great order; hence our present knowledge extends no farther back in time than to the Wasatch Eocene in America and equivalent horizons in Europe. Here we find its representatives not only sharply and distinctly separated from the Artiodactyls, the order to which the Perissodactyls are supposed to be most closely related, but some of the natural primary groups of the order are already definitely indicated. The origin of the order and even its true position relative to the Artiodactyla, therefore, are still unknown and are important problems, depending for solution on future exploration and discoveries in the fossil-bearing horizons of the basal Eocene or perhaps even an earlier period.

The acceptance in recent years of the very important Polyphyletic theory, or law, has led to the abandonment also of the monophyletic origin theory and the attempts to trace out direct ancestral lines, such as was so elaborately done by Marsh for the development of the horse. The polyphyletic theory has been verified by Osborn in his study of the Titanotheres and Rhinoceroses, and by Osborn and Gidley for the horses and their relatives of the Tertiary formations.

Thus the Titanotheres of the Oligocene, instead of being a diversified group derived from a single Eocene ancestor, are now known to belong to at least four contemporaneous phyla, represented by as many distinct types in the Eocene. Likewise the rhinoceroses show a polyphyletic origin,

[2] Bull. Amer. Mus. Nat. Hist., vol. ix, pp. 308-310.

while the great group now classed under Equidæ, comprising species from the Lower Wasatch up to and including the living horses, is divisible into four groups, or subfamilies, each containing several distinct phyla, which stand in more or less direct ancestral relationship to those of the next higher group, but between which there has not yet been found any species which exactly bridge the gap between the subfamilies as now classified.

The principal theories which may be said to be demonstrated in part, but still lack convincing proof, are the polyphyletic origin of the order and the use of dolicocephaly and brachycephaly for a standard of classification, as worked out by Osborn in the Titanotheres and Rhinoceroses. The present proposed phylogeny of the rhinoceroses and horses, especially as regards the derivation and true relationships of the subfamilies Hyracotheriinæ, Anchitheriinæ, and Protohippinæ, are problems in which study and investigations should be continued. To this end further explorations should be made for more and better material, especially in the Miocene and Pliocene formations, with a view to clearing up some of the more important questions of classification and relationships of both the horses and rhinoceroses of these periods. All the Eocene Perissodactyls except the Titanotheres are in need of further revision and study, and efforts should be made to secure additional material from the lower and basal Eocene formations. This should eventually do much to clear up the earlier ancestry of the great groups of the order, and give us a better understanding of their true relationships one to the other.

The importance of continued investigation in the Miocene, Pliocene, and Pleistocene should perhaps be especially emphasized, for here, with our modern methods of research, it now seems possible to trace at least approximately the origin and development of the living species of horses (including the asses and zebras) and rhinoceroses.

CARNIVORA AND RODENTIA

BY W. D. MATTHEW

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CARNIVORA

MATERIAL

The additions to our knowledge of American fossil Carnivora have been very large in the last decade. This is especially true of the Eocene Carnivora, not so much in number and variety as in the more complete knowledge of skull and skeleton.

A decade ago we were acquainted with the skull and skeleton of four Eocene Carnivora—Pachyæna, *Mesonyx*, *Oxyæna*, and *Patriofelis*. The remaining genera were known only from the dentition, and in most cases very little of that. Wortman's studies of the Eocene Carnivora of the Marsh Collection and the explorations and studies of the American Museum have added 14 genera to the list of those known from skull and more or less complete skeletons, while the number of new genera has been very little increased. Our knowledge of the Eocene Carnivora is thus placed upon a much firmer and more permanent foundation than would be possible with fragmentary material.

Most of this new material is from the Middle and Upper Eocene. Our knowledge of Lower, and especially of Basal Eocene, Carnivora is still based upon fragmentary data, and a great deal of it provisional.

The Oligocene Carnivora have also been placed upon a much more satisfactory footing during the last ten years. The principal types are represented by skulls or complete skeletons in the New York, Pittsburgh, Chicago, and other museums, several of which have been mounted. The published studies and descriptions, however, are by no means as full and complete as might be desired, and we are still largely dependent upon the already classic studies of Cope and Scott.

Almost nothing was known a decade ago of the Lower Miocene Carnivora, and comparatively little of the Middle and Upper Miocene. Great additions have since been made to the number of known types, and much of the new material has been remarkably complete. The finely preserved skeleton of *Phlaocyon* affords the missing link between the raccoons and the primitive dogs; the splendid skeleton of *Daphænodon*, recently described by Peterson, connects the aberrant Amphicyonids with the Oligocene *Daphænus*, while a remarkable and unsuspected variety of Mustelids is represented by skeletons and more fragmentary material in the Chicago, Pittsburgh, New York, Amherst, Yale, and Lincoln Museums. A great diversity of dogs is also represented by skulls and skeletons in one or another of these museums. The Miocene Felidæ are still almost unknown.

These Miocene Carnivora are now known from a great amount of

well preserved material which will repay a more extended study and enable us to revise the history of the American Carnivora of the later Tertiary.

Perhaps the most remarkable find of the decade is the great series of splendidly preserved skulls and skeletons of the great Sabre Tooth Tiger from the Californian Pleistocene. This will afford one of the most interesting studies in morphology and adaptation that could be desired. The other Carnivora associated with it are of quite subordinate importance, but will place our knowledge of American Pleistocene Carnivora upon a much sounder foundation than heretofore.

In this summary of progress in American Carnivora I have emphasized the importance of complete material as the necessary foundation for sound and permanent work. I may cite in contrast the state of our knowledge of the Carnivora of the European Tertiary, which is still based in great part upon a more or less imperfect acquaintance with the dentition of a vast variety of genera whose real affinities are often questionable in spite of the immense learning and exhaustive study that has been devoted to them by Dr. Schlosser and other high authorities. Very little has been added to the European Carnivora in recent years; the most important point is perhaps the recognition of the American genus *Pachyæna* in the Lower Eocene of France.

In the Oligocene of Egypt a remarkable fauna has been discovered through the efforts of the Geological Survey of Egypt, the British Museum, the American Museum of Natural History, and the Stuttgart Museum. The Carnivora of this fauna are all Creodonts of the family Hyænodontidæ, more or less closely related to the Upper Eocene Hyænodonts of Europe, and roughly equivalent to them in stage of evolution. This affords a striking contrast to the Tertiary fauna of South America, in which no true Carnivora are found, their place being taken, as in Australia, by specialized carnivorous Marsupials. The interpretation of this fact can not be discussed here.

A field well worth exploration is indicated by fossils obtained from the apothecary shops of China and described by Schlosser. This fauna is correlated with the Pliocene on faunal grounds, although such specimens as I have seen compare in their preservation rather with Miocene than with Pliocene fossils. The fauna is at all events a more directly ancestral fauna to the Pleistocene and modern Holarctic faunæ and contains fewer aberrant elements, than any other late Tertiary fauna which has been described. It may turn out to be really Miocene, its progressiveness being due to its nearness to the dominant centers of dispersal of the Tertiary Mammalia.

RESULTS GENERALLY ACCEPTED

1. The Eocene Carnivora comprise a number of groups of divergent specialization analogous in large part to the modern Carnivora. From one of these groups (Miacidæ) are derived all the later Tertiary and modern Carnivora by a second adaptive radiation. This confirms the views set forth by Scott and Osborn twenty years ago.

2. The Eocene Carnivora are not intermediate between Placental and Marsupial Carnivora, but are true placentals. The marsupial resemblances are due in part to inheritance of common primitive characters from a very remote common ancestry, but chiefly to parallel, or even convergent, evolution. The opposite view held fifty years ago by Gaudry, and more recently revived by Ameghino, Lydekker, and Wortman, is not substantiated by the evidence.

3. The Felidæ are not derived from *Palæonictis,* but from some unknown Eocene genus of Miacidæ.

4. The various families of Carnivora, both Creodonta and Fissipedia, are mostly common to the Palæarctic and Nearctic regions, but some are more abundant and varied in one, some in the other division. The Viverridæ are exclusively Palæarctic, the Procyonidæ Nearctic, until the later Tertiary, when each family invaded the regions to the south of it.

5. The African Oligocene Carnivora are all Hyænodontidæ. No evidence of other Creodont families or of modernized Carnivora. They are more primitive than their European contemporaries, but some are of divergent specialization.

6. The middle and later Tertiary Carnivora are nearly allied in the Palæarctic and Nearctic regions, and their evolution is partly upon parallel lines, partly by successive new types appearing from some common center of dispersal. The families had already become established in the Miocene, but in the Oligocene it is difficult to distinguish the phyla except upon evidence of the complete skeleton. The Oligocene Carnivora are mostly synthetic types, mingling characters which have since become peculiar to different families. The modern genera were established in the Pliocene and Pleistocene.

HYPOTHESES UNDER CONSIDERATION

1. Many of the basal Eocene Creodonts (Oxyclænidæ, Triisodontidæ) are of doubtful affinities. They may be Insectivora or of other orders.

2. The Mesonychidæ are not closely related to the rest of the Creodonta and show a considerable fundamental resemblance to the Eocene Artiodactyla. A revision of their relations is necessary.

3. Except for the Mesonychidæ, the tracing back of the phyla of Creodonta points to derivation from arboreal ancestry.

4. The geographical dispersal of the Carnivora appears to be from a Holarctic center and the various families are presumably derived from different dispersal points within that realm.

5. Derivation of the Felidæ from *Dinictis*, while the Machærodonts are derived from *Hoplophoneus*.

INVESTIGATIONS DESIRABLE

1. Basal Eocene Creodonts—skulls and skeletons to decide their affinities.

2. Eocene ancestors for the Felidæ. While derivable from the Miacidæ, this family is clearly not derivable from any known group of Miacidæ.

3. What is the real significance of the resemblances between Mesonychidæ and Artiodactyla? Does it mean that the Mesonychidæ are not Creodonts, but a flesh-eating specialization from the pro-Artiodactyls? or does it mean that the Artiodactyls are derived from Creodont ancestry?

4. What are the real affinities of the Mustelid-Canid-Viverrid group of European Oligocene Carnivora. Are they ancestral to all, or merely analogous to one or two of these three modern families? The problem can not be definitely settled on the dentition only.

5. What are the real affinities of the Ursidæ? The morphologic data point to Mustelid derivation. The paleontologic data seem to indicate a nearer affinity to the Canidæ, but are not altogether convincing. They are usually regarded as of old-world derivation through *Ursavus* and *Cephalogale*. But it must be remembered that exactly as good evidence might be adduced for deriving them from the American *Cynarctus* and *Cynodesmus*.

6. What is the derivation of the Hyænidæ? Is *Ictitherium* an annectant type indicating Viverrid affinities, or merely another case of convergence in dentition? Have they anything to do with *Aelurodon?* Here, again, the morphologic and paleontologic evidence are in apparent conflict, the latter pointing to close Viverrid affinities, the former to more remote Canid affinities.

Rodentia

MATERIAL

The overwhelming predominance of rodents among modern mammals is well known. They are by no means so common as fossils, and of those

which are on record comparatively few are known from the complete skull or skeleton, most of them only from parts of the jaws. The most important additions of the last decade are:

1. Complete skeletons and series of skulls of several Eocene Rodentia of North America.

2. Skeletons and skulls of the principal Miocene rodents of South America.

3. Skulls and skeletons of *Steneofiber* and *Mylagaulus* from the North American Miocene and Pliocene.

4. Skulls of various Oligocene rodents from North America and remains of rodents from the Fayûm fauna in Egypt.

PRINCIPAL CONCLUSIONS FROM THE STUDY OF THE MATERIAL

1. The Lagomorpha have very little, if anything, to do with the remaining rodents. They have changed but little since the Oligocene, and their earlier history is totally unknown.

2. The Simplicidentate rodents are a natural group derived from the Eocene Ischyromyidæ.

3. The Tillodontia have nothing to do with the Rodentia, but are probably related to the early Insectivora. The same is true of the Proglires. Palæontology throws no light on the derivation of the Eocene Rodentia or their affinities to other orders.

4. The Miocene rodents of South America are all Hystricomorpha. The Theridomyidæ of the early Tertiary of Europe appear to be transitional from Ischyromyidæ to Hystricomorpha, but their relations to the Miocene Hystricomorphs of South America are not yet clear.

5. *Castoroides* is a Sciuromorph related to the true beavers. Its Chinchilla resemblances are wholly due to parallelism. *Amblyrhiza*, on the other hand, is probably related to the Chinchillas.

6. *Dæmonelix* is not a fossil plant; most of the forms attributed to it are probably fossilized burrows of some rodent, presumably *Steneofiber*.

MOST IMPORTANT INVESTIGATIONS DESIRABLE IN THIS LINE

1. The origin and affinities of the Duplicidentata.

2. A thorough monographing of the Eocene and Oligocene rodents and the light they throw on the origin and relationships of the Simplicidentate families.

3. Reinvestigation of the Theridomyidæ in their relations to the Santa Cruz and other South American Hystricomorphs; and if they are ancestors of the latter, a satisfactory explanation of their migration.

4. Re-study of *Dæmonelix* and a more exact and conclusive explanation of the formation of these "burrows."

5. Our acquaintance with the later Miocene and Pliocene Rodentia in this country is very imperfect. More, and more complete material is very greatly needed.

6. A thorough study of the evolution of the cheek teeth in rodents, which will enable us to distinguish between parallelism and affinity more satisfactorily than has yet been done.

MARSUPIALS, INSECTIVORES, AND PRIMATES

BY WILLIAM K. GREGORY

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General Publications

In a review of the progress of the last ten years in the field of the Marsupials, Insectivores, and Primates, it seems appropriate to record the publication of several works of a general character, which have dealt with these orders in relation to the mammals as a whole. First in importance is Prof. Max Weber's books, "Die Säugetiere," published in 1904. This is by far the greatest modern work on the mammals, and it makes available for the paleontologist the far-reaching but hitherto widely scattered and uncoördinated results of comparative anatomical research.

In a recent work by the present writer[1] the orders under consideration have been discussed in some detail, and in their relations to other groups, from the point of view of phylogeny and classification.

A work by van Kampen[2] on the tympanic region of the mammalian skull, although dealing with a restricted problem, is of great value in phylogenetic questions.

[1] The Orders of Mammals. Bull. Amer. Mus. of Nat. Hist., vol. xxvii, 1910.

[2] Die Tympanalgegend des Säugetierschädels. Morphol. Jahrb., Bd. xxi, 1905.

Marsupialia

The memoir by Bensley, "On the Evolution of the Australian Marsupialia" (1903) is a notable attempt to interpret the Marsupials from the viewpoint of adaptation and phylogeny. Dollo had shown that the peculiar syndactylous modification of the third and fourth digits of the pes in Australian Diprotodonts is very probably a reminiscence of former arboreal habits. Bensley extended Dollo's observation and showed that even among the still existing Marsupials there are many gradations between the normal five-toed pes of the Didelphids and the highly specialized pes of the kangaroos. He also described the supposed changes in the dentition, starting with the small insectivorous didelphids with so-called tritubercular dentition, passing through various intermediate types in the several lines and culminating respectively in the specialized carnivorous types with sectorial molars, in the specialized herbivorous types with bilophodont molars, in the root-eating wombats with rodent-like dentition, and so forth.

The hypothesis according to which these results were worked out was that the tritubercular dentition had been the starting point in the Australian Marsupials as in the Placentals, and that the steps by which various specializations had been attained in the Placentals had also been paralleled more or less in the Marsupials.

The scant paleontological data are by no means unfavorable to Bensley's conclusion.[3] The didelphoid type, which he regards as the ancestral form, had a wide northern distribution in the Oligocene, Eocene, and very likely also in the Cretaceous. The Tasmanian Tertiary genus *Wynyardia* of Spencer, known from a well preserved skull, which unfortunately lacks the teeth, appears to connect the diprotodont with the polyprotodont type.[4]

The close relationship of diprotodonts and polyprotodonts is virtually proven by the uniform and highly characteristic arrangement of the cranial foramina,[5] by the peculiar form of the orbitosphenoid,[6] and by many other important agreements, both in structure and in development,[7] so that it would not be surprising if Bensley should be proven to be right in inferring that the Australian marsupial fauna is of Tertiary derivation and evolution.

Passing to the consideration of works on fossil Marsupials, we notice

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[3] Gregory, op. cit., pp. 205-206.
[4] Ibid., pp. 214-215.
[5] Ibid., pp. 222-225.
[6] Ibid., p. 245.
[7] Ibid., p. 221.

first the publication of Dr. Sinclair's memoir on the Marsupials of the Santa Cruz formation.[8] Carefully describing the fine material secured by Hatcher and Peterson, Sinclair was apparently enabled to settle the vexed question whether the "Sparassodonts" of Ameghino, including *Borhyæna* and its allies, were Marsupials or Creodonts. Because these genera were Creodont-like in form of skull and teeth, and because they lacked certain "Marsupial" characteristics, such as epipubic bones and palatal vacuities, it had been supposed that they must be Creodonts, or at least must connect the Creodonts with the Carnivorous Marsupials. But Sinclair's analysis of their characters resulted in a very strong case for the view that the Sparassodonts were true Polyprotodont Marsupials, and widely removed from the Creodonts.

A single outstanding difficulty, however, has led Lydekker in his Encyclopædia Britannica articles to reject Sinclair's conclusions and to return to the view that the Sparassodonts are Creodonts. While Dr. Sinclair's memoir was in press, Mr. C. S. Tomes published in the Proceedings of the Zoölogical Society[9] an important article, in which he showed that in the histological structure of the enamel *Borhyæna* differed quite radically from the Carnivorous Marsupials, and agreed with the Inadaptive Creodonts and the modern Fissipedia; that is to say, Tomes found that in the single premolar of *Borhyæna* available for examination there were no dentine tubules in the enamel, unlike other Marsupials, and the enamel prisms were gathered together into bundles which were twisted and interlaced in a manner recalling the frayed out strands of a rope—an arrangement precisely similar to that in the Inadaptive Creodonts and modern Carnivores, but not found in the Adaptive Creodont *Didymictis* or in the Oligocene Cynoid *Cynodictis*. Matthew,[10] in analyzing these results, held that this was merely another character in which *Borhyæna* had progressed beyond the other Carnivorous Marsupials in paralleling the Placental Carnivores, and that this and other resemblances to the latter groups were of far less weight than the many true marsupial characters noted by Sinclair.

It is greatly to be desired that Mr. Tomes's investigations should be extended to include the histological structure of the enamel in the less specialized Sparassodonts *Cladosictis* and its allies, as well as in fossil and recent Didelphids and other groups of mammals. In the meanwhile the reviewer can not help feeling that Sinclair and Matthew are entirely right in referring the Sparassodonts to the Marsupialia.

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[8] Rept. Princeton Univ. Exped. to Patagonia, vol. iv, pt. iii, 1906.
[9] 1906, vol. i, pp. 45-58.
[10] Geological Magazine, n. s. (IV), vol. iv, 1907, pp. 531-535.

Although *Borhyæna* has lost so many marsupial characteristics, its allies, *Cladosictis* and *Amphiproviverra,* retain many extremely important ones. The alisphenoid bulla, the form and relations of the malar, the basicranial region, the dental formula, the strongly inflected angle of the jaw, the separate intercentrum of the atlas, the seventh cervical pierced by the vertebrarterial canal, the form of the astragalus, the small size of the lunar—all these and many others noted by Sinclair betoken Marsupial, not Creodont, affinities.

In view of the many important agreements shown by the Sparassodonts with *Thylacinus,* including a peculiar displacement of the ectocuneiform beneath the cuboid, Sinclair referred the group to the family Thylacinidæ; but it has been suggested by Matthew that this does not necessarily imply that the Sparassodonts are either descended from or ancestral to their Tasmanian allies, but that the Borhyænidæ and the true Thylacinidæ may represent closely related, but still parallel, lines, independently derived from early northern didelphoids. This hypothesis, especially on account of its paleogeographical implications, is worthy of careful examination.

In the same memoir Dr. Sinclair described the remains of a number of Epanorthids or Cænolestoids, figured the skull of *Cœnolestes,* the sole surviving member of this family, and showed that the Santa Cruz *Halmarhiphus* appears to be ancestral to *Cœnolestes* and also occasionally retains the full didelphid tooth formula. Studies of the skull of *Cœnolestes* by Miss Dederer[11] and the present writer[12] indicate that we have here to do not with a true Diprotodont, but with the representative of a distinct suborder, the Paucituberculata of Ameghino, derived from Polyprotodonts peculiar to South America and paralling in dentition the smaller Australian phalangers.*

Multituberculata

To our fortunate colleague, Mr. Gidley, has been accorded the privilege of describing† a well preserved skull associated with the lower jaw, some vertebræ and limb bones, of *Ptilodus,* a basal Eocene survivor of the Mesozoic Plagiaulacidæ, a family hitherto known only from disassociated jaws and teeth, and about whose affinities Owen, Falconer, Cope, and many others had disputed almost in vain. At first glance few zoolo-

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[11] American Naturalist, vol. xliii, 1909, pp. 614-618.

[12] The Orders of Mammals, p. 211.

* Broom, in a recent paper "On the Affinities of Cænolestes" (Proc. Linn. Soc. N. S. Wales, 1911, vol. xxxvi, part 2, pp. 315-320), concludes that *Cœnolestes* is a true polyprotodont, not deserving even subordinal separation.

† Proc. U. S. Nat. Mus., vol. xxxvi, 1909, pp. 611-626, with plate 70.

gists would hesitate to refer this skull to the Diprotodontia; but, remembering the great geological age of the Plagiaulacidæ and the probably late origin of the true Diprotodontia, recognizing the marked differences in the dental formula and form of the cheek teeth, and mindful of the pitfalls of convergence and parallelism, especially among related groups, we can only say that in *Ptilodus* the broad palate, with widely open vacuities, the stout jugal reaching back to the glenoid, the inflexion of the jaw—these are characters which undoubtedly betoken some degree of kinship with the Marsupialia, but hardly prove that the Plagiaulacidæ are Diprotodontia in the strict sense. Indeed, Broom[13] has argued that the Plagiaulacidæ may prove to be an offshoot from the early Prototheria—that is, from the primitive group with Monotreme-like coracoids and oviparous habits, which there is reason to believe[14] was ancestral both to the modern Monotremes and to the Marsupials.

The extinct Patagonian genus *Polydolops* and its allies, which were described by Ameghino as Multituberculates, appear to differ from the true Multituberculates in some important particulars, and the writer[15] has adduced evidence tending to show that they are "pseudo-Multituberculates," derived perhaps from some early Epanorthids resembling *Abderites*.

PANTOTHERIA

With regard to the Mesozoic mammals of the order Pantotheria or Trituberculata, which are often referred to the Marsupialia in the broad sense, very little new material has come to light during the past ten years; but these groups have been more or less reconsidered in their bearing on the theory of trituberculy by Osborn[16] (1907), Gidley[17] (1909), and the present writer[18] (1910).

The origin of the so-called tritubercular molar has continued to challenge the ingenuity of authors. Gidley, developing Wortman's[19] "premolar analogy" theory, holds that the so-called protocone of the upper molar has resulted from the upgrowth of a basal cingulum, like the hypocene, and that it has grown up *pari passu* with the talonid of the lower molars, while the present writer[20] thinks it more probable that in the

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[13] On Tritylodon, and on the Relationships of the Multituberculata. Proc. Zool. Soc., 1910, pp. 763-768.

[14] Gregory, op. cit., pp. 157, 160, 148.

[15] Ibid., pp. 211-214.

[16] Evolution of Mammalian Molar Teeth, 8vo, New York, 1907.

[17] Proc. Washington Acad. Sci., vol. viii, 1906, pp. 91-110.

[18] Gregory, op. cit., 1910, pp. 181-194.

[19] Studies of Eocene Mammalia, etc. Amer. Jour. Sci., vol. xiv, p. 94; ibid., vol. xvi, pp. 215-218.

[20] Op. cit., pp. 184-189.

remote predecessors even of the Mesozoic Trituberculata the upper molars were already widened *transversely* as in certain Theriodonts, and that the inner part, later giving rise to a distinct protocone, fitted behind the summit of the small, heelless, lower molars. But while opinions differ as to the ultimate origin of the "tritubercular" type or types, and while the homologies of the cusps may not be as universal as it was formerly believed, yet there can now be very little doubt that many or perhaps all placental orders at one time passed through a stage in which the upper molars were trigonal, the lower tuberculosectorial. For this conclusion strong evidence was adduced by Osborn and the writer in 1907.[21] And the conclusion that the trigonal-tuberculosectorial types is primitive is somewhat strengthened by the independent evidence that most placental orders have been derived from forms having a dental formula of $\frac{3 \,.\, 1 \,.\, 4 \,.\, 3 \,.}{3 \,.\, 1 \,.\, 4 \,.\, 3 \,.}$; for, wherever clear traces of this formula are observed, then the molars of the earlier members of such groups show a distinct approach either to the "sexitubercular" molars of the Condylarths or to the trigonal molars of the Insectivore-Creodont group; in other words, they lead back toward the trigonal-tuberculosectorial type. This is notably the case with the extinct South America "Ungulates," many of which retain the complete placental formula in spite of diverse specialization in the form of the teeth. And although in the hypsodont forms the so-called tritubercular pattern is largely obliterated, yet in the small primitive bunodont types from the *Notostylops* beds the tritubercular pattern becomes very clear.[22] We may even go further and say that whenever the dentition of the early members of a race approaches the normal Placental arrangement of the incisors, canines, and simple premolars, then that race is leading back toward omnivorous or insectivorous-carnivorous types with trigonal-tuberculo-sectorial molars.

INSECTIVORA

In the field of recent Insectivores, Leche has continued his important series of monographs, the section published in 1907[23] dealing with the dentition, anatomy, and osteology of the Zalambdodonts. Weber's[24] treatment of the Insectivora is also noteworthy. The genetic relations of the Insectivora were considered in some detail by the writer in 1910[25] and some of his principal conclusions regarding the Insectivora were as follows:

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[21] Evolution of Mammalian Molar Teeth, pp. 91-192.
[22] Gregory, op. cit., pp. 373, 376, 379.
[23] Chuns Zoologica, 4to, pp. 1-157, p. 11, i-iv.
[24] Die Saügetiere.
[25] Op. cit., pp. 231-292.

From a detailed analysis of the osteology and other features of the various families it was concluded that Weber was entirely right in adopting Haeckel's division of the Insectivora into two sharply separated suborders, namely, the Lipotyphla, embracing the Zalambdodonts, Leptictids, Erinaceids, Moles, and Shrews, and the Menotyphla, including the Tupaiidæ and Macroscelididæ. It was further shown that the Menotyphla approach the Lemuroids so closely that possibly they may be truly related to the Primates, although the possibilities of convergence must not be forgotten. In the same work the Chrysochlorids were carefully compared with the Marsupial "mole" *Notoryctes*, and the conclusion of Weber and Leche was confirmed that the numerous resemblances between these two families were very largely secondary. The confusing homologies of the molar cusps in the different families were discussed. By setting aside the specializations peculiar to the different families and by putting together the characters regarded as primitive, an attempt was made to reconstruct the primitive Insectivore, and it was concluded that such a type would be structurally ancestral to the Primates, Creodonts, Condylarths, Ungulates and related groups, and possibly also to the Rodents. Matthew's view[26] that the stem Placentals were arboreal forms was supported. The Tillodonts also were referred to the Insectivore-Creodont stem and their supposed connection with the rodents was denied.

To our knowledge of Tertiary Insectivora very notable additions have been made. Douglas,[27] under the name *Xenotherium*, described in 1906 a small skull from the Oligocene of Montana which unfortunately lacked the teeth. This genus was later referred by Matthew[28] to the Chrysochloridæ, along with certain other little-known forms from the Titanotherium beds. That *Xenotherium* is a Chrysochloroid is shown by many features, but especially by the characteristic form and relations of the auditory bulla. The extinct and previously little known Patagonian genus *Necrolestes* of Ameghino was more fully described in 1904 by Professor Scott,[29] who showed that it is probably an offshoot from some early member of the family which was at the same time the ancestor of *Chrysochloris*.

The paleogeographical bearing of these discoveries is of considerable importance, and not less so is the description by Matthew[30] of the genus *Apternodus*, a member of the Centetidæ. *Apternodus*, while slightly

[26] American Naturalist, 1904, pp. 811-818.

[27] Mem. Carnegie Mus., vol. ii, no. 5, pp. 203-223, pl. xxii.

[28] Science, n. s., vol. xxiv, 1906, pp. 786-788.

[29] Rept. Princeton Univ. Exped. to Patagonia, vol. v, pp. 365-383, pl. lxiv, figs. 1-5.

[30] Bull. Amer. Mus. Nat. Hist., vol. xix, 1903, p. 225; ibid., vol. xxviii, 1910, pp. 33-36, pl. vi.

more primitive in its dentition, is distinguished from the living *Microgale* of Madagascar chiefly by the greater external flattening and enlargement of the squamosal.

Of the Oligocene Leptictidæ, Douglass[31] has described some fine skulls and portions of the post-cranial skeleton. In the Erinaceidæ the genus *Proterix* of Matthew[32] connects the hedgehogs with the Leptictidæ. Among the Talpidæ Matthew[33] has described the skull of the Upper Oligocene genus *Proscalops*, and to this family he has very provisionally referred a large variety of teeth which are described and figured in his important monograph on the Carnivora and Insectivora of the Bridger Basin.[34] One of these specimens, the type of *Entomolestes grangeri* Matthew, so far as indicated by the dentition, is structurally ancestral to the Tupaiidæ.

The genus *Pantolestes*, from the Bridger Eocene, founded by Cope on very scant material and referred by him to the Artiodactyla, has been redescribed from much better material by Matthew,[35] who refers the Pantolestidæ to the Insectivora, and shows that they combine Insectivore, Creodont, and Pinniped features.

Another puzzling synthetic type referred to the Insectivora is the Eocene *Hyopsodus*, a form which during the last ten years has become much better known through the researches of Osborn,[36] Wortman,[37] and especially of Matthew.[38] These three authors have also discussed the position of the Mixodectidæ, and the probable conclusion is that this family is not related to the rodents, but is either lemuroid or "insectivore." Possibly related to the Mixodectidæ is the family Apatemyidæ of Matthew,[39] known from teeth and jaws from the Bridger Basin.

If all these doubtful groups are to be included in the single order Insectivora, then the boundaries of that order become rather uncertain and the exact relationships of the Pantolestoidea, Hyopsodonta, and Mixodectidæ to the Lipotyphla, Menotyphla, and other groups constitute a promising field for future study.

PRIMATES

The varied Primates of the American Eocene, known chiefly from

[31] Mem. Carnegie Mus., vol. ii, no. 5, 1906, pp. 203-223, pl. xxii.
[32] Bull. Amer. Mus. Nat. Hist., vol. xix, 1903, pp. 227-229.
[33] Mem. Amer. Mus. Nat. Hist., vol. ix, pt. vi, 1909, pl. xlix, fig. 5, pl. li, figs. 3, 4.
[34] Ibid., pp. 543-546.
[35] Mem. Amer. Mus. Nat. Hist., vol. ix, pt. vi, 1909, pp. 522-534.
[36] Bull. Amer. Mus. Nat. Hist., vol. xvi, pp. 169-214.
[37] Amer. Jour. Sci., vol. 15, 1903, pp. 162-163.
[38] Mem. Amer. Mus. Nat. Hist., vol. ix, pt. vi, 1909, pp. 508-522.
[39] Ibid., pp. 543-546.

jaws and teeth described by Leidy, Cope, Marsh and others, had become the basis of a confused and extensive synonymy. In a revision of this group by Osborn[40] in 1902, many of the more important types were figured, the species were arranged according to geological level, and the synonymy and literature were made accessible for future research. This was followed in 1903 by the contributions of Dr. Wortman[41] on the Eocene Primates of the Marsh Collection of the Peabody Museum. Here we find many carefully executed figures of the skull and dentition of recent and fossil Primates, and, especially, original and stimulating views regarding the relationships of all the families of Primates, the origin of the order and the origin of mankind. But until the rich undescribed material of Eocene Primates in the American Museum has been thoroughly studied, the writer is not in a position to offer any effective criticism of Dr. Wortman's conclusions. These have been reviewed by Dr. Schlosser,* who has given a brief reclassification of the group and has shown that *Necrolemur* resembles *Anaptomorphus* in the skeleton.

In this connection it may not be inappropriate to note that Dr. D. G. Elliot has now in press a monograph on the Primates which will contain an extensive series of photographs of the skull and dentition of the recent forms.

The researches of Forsyth Major, Grandidier,[42] Standing,[43] and others on the extinct lemurs of Madagascar show that some of the short-faced genera closely approach the Anthropoidea in skull characters. Standing concludes that the Lemuroidea and Anthropoidea are closely related and that the modern Lemuroids have been derived by retrogressive changes from a more pithecoid type. *Chiromys* and *Megaladapis* are said to be closely related with the modern Indrisinæ. These conclusions are also supported by Elliot Smith[44] from his studies on the brain and brain casts.

In the field of the Anthropoidea the most notable event is the description by Schlosser† of two new genera, *Parapithecus* and *Propliopithecus*, founded on lower jaws from the Oligocene of the Fayûm. In dental formula, characters of the teeth, and shape of the jaw, these two genera, according to Schlosser, represent successive stages leading from the Anaptomorphidæ and Tarsiidæ to *Pliopithecus* and the Simiidæ. Schlosser even regards *Propliopithecus* as certainly the ancestor of *Plio-*

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[40] Bull. Amer. Mus. Nat. Hist., vol. xvi, pp. 169-214.
[41] Amer. Jour. Sci., vol. 15, 1903.
* Neues Jahrb. f. Min., Geol. u. Pal., Festband, 1908, p. 201.
[42] Recherches sur les Lemuriens disparus. Nouv. Arch. du Mus., 4e ser., tome vii, 1905.
[43] Trans. Zool. Soc., vol. xviii, pt. ii, 1908, pp. 59-162, pll. x-xvii.
[44] Trans. Zool. Soc., vol. xviii, pt. ii, 1908, pp. 163-177.
† Beitr. z. Paläont. u. Geol. Osterreach-Ung. u. d. Orients, Bd. xxiv, pp. 52-64.

pithecus and probably of all Simiidæ and Hominidæ. And while no conservative zoologist, on account of the great importance of this conclusion, will be over hasty in accepting it on faith, still a comparison of Schlosser's figures of these specimens with casts or originals of various human types and of Tertiary and recent Primates will enable the individual student to judge himself of the force of Schlosser's argument.

The discoveries of the early human skulls in France and of the human jaw described by Schoetensack as *Homo heidelbergensis* are so fresh in the minds of all zoologists that their enormous importance need not be dwelt upon. There are, however, one or two points about this Heidelberg jaw which are especially noteworthy.

It is well known that although the massive jaw is more or less suggestive of the Anthropoids, the teeth are typically human. This human character is especially evident in the form of the canines and premolars. The canines are rounded and project but little above the level of the surrounding teeth, and the first premolar is a true bicuspid; whereas in the typical Anthropoids, both Tertiary and recent, the canine is large and very prominent, and the first premolar is large and compressed. But if comparison be made with Schlosser's new genus *Propliopithecus,* above mentioned, it will be seen that in the latter the canine and premolars are more or less intermediate in form between those of the Heidelberg or other human jaw and the chimpanzee; that is to say, as compared with the chimpanzee, the canine in *Propliopithecus* is small and does not project very far above the level of the premolars, while the first premolar is not large and compressed, but small and almost bicuspid. Thus, not only in the form of the molars, but also in the form of the canines and premolars, *Propliopithecus* is apparently less specialized than either the Heidelberg man or the chimpanzee.

Conclusion

To state the obvious conclusion, the very substantial and encouraging advances of the past decade in our knowledge of the groups under consideration emphasize the importance of these orders in the general problems of mammalian evolution. The great need is ever not only for renewed paleontological discovery, but for a closer synthesis of the results of anatomical and paleontological research.

MARINE MAMMALS

BY FREDERICK W. TRUE [1]

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Progress made during the past Decade

The term Marine Mammals is ecological rather than systematic. Under it are usually comprised several quite distinct groups of animals—the whales and porpoises, or Cetacea; the sea-cows, or Sirenia; the zeuglodonts, or Zeuglodontia; and the seals, walruses, and sea-lions, or Pinnipedia.

While the investigations of the last decade relative to these animals have been extensive and important—on the whole, more so than those of any comparable preceding period—it can not be said that the present knowledge of the fossil representation of any of the groups is fairly complete.

The greatest progress, on the whole, has been made with regard to cetaceans, closely followed by the zeuglodonts and sirenians, while the knowledge of the seals and walruses has advanced but little, and that of the sea-lions still less. I speak now both with reference to the forms which actually inhabited the earth in former epochs and with reference to the ancestry of existing forms.

As regards cetaceans, the number of forms represented by names in printed lists is very large, but many of these are based on inadequate material, and on that account they can not be said to be well known. Their osteology can not be completely worked out, and their relationships are a matter of surmise rather than of demonstration. Nevertheless, chiefly through the investigations of the last decade, the families of toothed whales have been delimited with a considerable degree of accuracy, and their relations to each other and their phylogeny have been measurably determined. The same can not be said regarding the whalebone whales. Although the European material, at least, is extensive and is of a character which has permitted the quite complete description and illustration of the osteology of different forms, their relationships and

[1] Introduced by C. D. Walcott.

phylogeny have received but little critical study, and the limits of the various groups are not well understood.

The National Museum has recently obtained skulls of several forms of toothed whales not previously recognized as occurring in America, as well as large numbers of other skeletal parts of both toothed whales and whalebone whales. The Geological Survey of Maryland and the University of California have collected some interesting material in connection with their various paleontological investigations. The Geological Museum of the University of Padua contains some interesting specimens of fossil toothed whales, recently collected by Doctor Dal Piaz in the Italian Miocene. Single specimens of great interest are scattered through the museums of Bologna, Budapest, Vienna, Saint Petersburg, Brussels, and the museums of the United States and Argentina.

The knowledge of the zeuglodonts has received very great accessions during the decade, chiefly through the discoveries in the Eocene of Egypt, and their evolutionary history and their principal representatives may be said to be well known. The most important recent collections from Africa are in the Geological Museum at Cairo, the museums of Frankfort-on-the-Main, Munich, Stuttgart, and London. Something has been done to make the American forms better known, and a fine skeleton of the great *Zeuglodon cetoides* has been mounted by the National Museum.

Much has been learned regarding primitive Sirenians during the decade, and the ancestry of the group has been traced back to the Lower Middle Eocene. The most important collections are those obtained in Egypt along with the zeuglodonts. They are preserved in the Geological Museum at Cairo, in the British Museum, and, I believe, in the museums of Munich and Stuttgart.

Knowledge of the pinnipeds has not progressed materially during the decade. We have learned definitely, however, that seals and walruses occurred in the Miocene of our Atlantic coast, and seals and sea-lions in the Miocene of the coast of Oregon. The American material collected, though important, is limited in extent.

Theories accepted and rejected in recent Years

The theory that primitive mammals were cetoid in character has, I believe, been definitely rejected; also that there is any direct relationship between Cetacea and Sirenia.

That the toothed whales are directly derived from small primitive zeuglodonts (but probably not from any known form) has been generally accepted; and this view, with various modifications, is, I think, the pre-

vailing one at present, although opinions are not entirely unanimous. The origin of the whalebone whales is not known, though it is recognized that their ancestors were toothed forms.

The notion, recently promulgated, that the large whales are direct descendants of large marine reptiles of similar form is treated somewhat in the light of a paleontological jest.

The idea that the Cetacea are derived from pig-like mammals is, I believe, no longer entertained.

That the existing Sirenia were derived from forms with four functional legs has been demonstrated, and that the group had common ancestors with the Proboscidea seems to be generally accepted at present.

Hypotheses on Trial

It has been shown that cetaceans have some resemblances to edentates, but there are no known fossil forms, I believe, that strengthen the idea that these similarities are genetic.

As to the zeuglodonts, the weight of opinion seems to be that they are *descendants* of creodonts, but some consider that they actually *are* aquatic creodonts. This view is opposed by others, who think that the zeuglodonts may quite as well be descendants of insectivores.

Two hypotheses regarding the origin of the pinnipeds find adherents. The one most strongly advocated is that they are descended from creodonts. The other is that they are derived from bear-like fissiped carnivora.

The hypothesis that the cetaceans, or some groups of them, were protected by an armor of bony scales, and that *Zeuglodon* had such an armor is at present in controversy. It has been demonstrated that some recent porpoises have such scales on the dorsal fin and some fossil species had them on the flippers.

It has been inferred, but not demonstrated, that the walruses are derived from some primitive form of sea-lion.

Important Investigations and Explorations which should be made

It is very desirable that further collections of the American zeuglodonts should be made, and that a full and well illustrated description of *Z. cetoides* should be published.

It is especially important that the Oligocene formation of the southeastern United States, and particularly certain areas in South Carolina, should be searched for primitive cetaceans, which will quite surely be

found there. The Miocene formation all along the South Atlantic seaboard is a practically unworked mine of fossil cetaceans, sirenians, and, to some degree, of pinnipeds also.

The fossil mammalia described in earlier years from Bessarabia so strongly resemble those of Maryland that new collections from that region would be of great interest.

It is extremely desirable that the types and other important specimens of fossil cetaceans in the Saint Petersburg Museum should be reexamined, and that photographic figures of them be published.

A monograph of the genus *Squalodon* and its allies is of the highest importance.

A résumé of existing knowledge of American fossil sirenians is much to be desired.

PALEOZOIC REPTILIA AND AMPHIBIA

BY E. C. CASE

The earliest work on Paleozoic reptiles and amphibians to take definite form was the work of Owen, Huxley, and Dawson on the material from England, Ireland, South Africa, and Canada, now preserved in the British Museum of Natural History and the Museum of Practical Geology in London; that of Gaudry on the fossils from the Permian of Autun in France, now in the Museum of the Jardin des Plantes in Paris, and that of Cope on his collections from Texas, now in the possession of the American Museum of Natural History in New York. Later came the work of Fritsch on the Permian remains from the Pilsen basin and Kuonova in Bohemia, now in the Prague Museum; that of Credner on the discoveries of Branchiosaurus and related forms from the vicinity of Dresden, now in the Museum of the Imperial Geological Survey at Leipzig, and Seeley's extensive "Researches on the Structure, Organization, and Classification of the Reptilia," dealing largely with the fossils from the Permian of South Africa, preserved in the British Museum of Natural History and the South African Museum at Cape Town.

These collections and the work on them led, finally, to the formulation of two important generalizations. First, Baur's paper "The Stegocephali, a phylogenetic study," published in the Anatomischer Antzeiger in 1896, which presents the conclusive arguments for the derivation of the Stegocephalia from the Crossopterygian fishes. Second, the formulation and support by Cope and Baur of the theory that the primitive reptiles Cotylosauria were derived directly from the Stegocephalia by the appearance of a single occipital condyle and the loss of the parasphenoid bone,

and that the development of the reptilian phylum from such a primitive form was to be most clearly traced in the condition of the temporal openings of the skull. This theory assumed that two openings appeared in the temporal region, separated by a narrow bar of bone and the lower one bordered by an equally narrow bar below. Two lines were supposed to have sprung from the primitive form; one, in which the two openings remained, either actually or potentially, and another in which the lower opening disappeared by the approximation of the two bars. The rhyncocephalian *Sphenodon* was regarded as an archaic type, representing the normal condition of the Permo-Triassic reptiles. This idea dominated the minds of all paleontologists interested in the primitive reptiles for many years and culminated in the important paper by Osborn, the "Reptilian subclasses Diapsida and Synapsida and the early history of the Diaptosauria."

A second period of activity may be said to have started with the beginning of collection by the University of Chicago in Texas, under the direction of Doctor Baur; this work has been continued and the American Museum has added considerably to its material in recent years. The formation of these collections attracted the attention of foreign workers, and in 1895 Broili made, with Sternberg, a trip into Texas, the results of which were carried to Munich. During the last summer von Huene purchased a collection from Sternberg, said to be very fine, which will go to Tubingen. During the same years came the discoveries of Amalitzky on the North Dwina River in Russia and the beginning of Broom's work in South Africa. Amalitzky's material has not, unfortunately, been worked up; a few specimens have been cleaned and mounted, but the scientific results from this most promising field are yet to come.

The results of the second period of activity have been, first, to support and later to question the theory on which most of the work was based. Starting with the assumption that the rhyncocephalian type is primitive, and so regarded as a strong guide on the path of research, many workers have been forced to the conclusion that the beautiful and simple conception of the development of the double and single arched reptilian skulls from a common ancestor can no longer be accounted sufficient. Repeated examples have shown the inadequacy of the theory, and now we can only say that while the morphology of the posterior region of the reptilian skull is still our most useful guide to the relationships of the reptiles, the idea of the development of a primitive two-arched type directly from a completely roofed form and then a differentiation into more specialized forms is far from proven.

The upper of the two temporal openings occurs between the squamosal and the prosquamosal and postorbital, the lower between the latter and the jugal and quadratojugal. It has been shown that, with the exception of *Pantylus*, no Cotylosaur has more than two bones below the parietal in the temporal region, the squamosal and the prosquamosal or quadratojugal. It is evident that the two openings could not have originated in such forms. *Pantylus* has the three bones, and the two openings might have appeared in such a form, but *Pantylus* is one of the most specialized of the Cotylosaurs and can not be placed in an ancestral position. If the theory of the primitive double-arched condition is to prevail, it must be supported by the discovery of a generalized Cotylosaur with the bones, as in *Pantylus*. No such form is known and there is an enormous hiatus in the evidence. At present it seems more probable that *Pantylus* is a specialized departure from the primitive stock, with but two bones in the temporal region.

On the other hand, it has been contended that the Pelycosaurs are two arched forms of the assumed primitive stock; this has been seriously questioned by Broom and von Huene, and it must be admitted that some Pelycosaurs are single arched, and that in *Dimetrodon*, even, the evidence is not conclusive. Last summer a joint expedition from the universities of Chicago and Michigan into New Mexico recovered a nearly complete skeleton of *Ophiacodon*, a primitive Pelycosaur, in which the two temporal openings are distinctly present. It may be that the weight of evidence is on the return swing toward the original theory.

The inadequacy of the theory has led to the formulation by Broom and von Huene of somewhat complicated and tentative theories to account for the different types of skull structure as independent developments from the Cotylosaurs. These have not yet been worked into definite form. More evidence is the great desideratum, and our achievements in this line are not inconsiderable. The confusion resulting from pioneer work in America has been in large measure, I hope, cleared up. Broom has performed a like service for the South African forms. Thevenin is busy with the French forms. The collections of the University of Chicago in the last ten years have been wonderfully rich. The American Museum has added much to its original material. The expedition of last summer into New Mexico brought back much of value, which, added to that which has long lain forgotten in the Yale Museum, throws a flood of light on the fauna of a new locality. Moody is busy on a monograph of the fossil amphibians of North America. Broom is still actively collecting, and Doctor Watson, of the University of Manchester, in England, has started on a collecting trip to South Africa.

Though the work of the last few years has been inimical to our most cherished theory, we can point to some positive results. Our knowledge of the osteology of the Paleozoic amphibians and reptiles has been enormously increased; we are coming to a realization of the great abundance and variety of life in the early periods; the habits, distribution, and relationships are all coming to be better understood, and we can soon hope to have a basis for enduring hypotheses of development. Even now we know that the connecting link between the amphibians and reptiles is well understood. Broili believed that *Seymouria* was an amphibian until he saw the palate; *Lysorophus* is called both amphibian and reptile because the condition of the occipital condyle is in dispute; *Trematops* and *Cacops* have vestigial parasphenoids. But these are all highly specialized forms; when we find a small, generalized amphibian in which we can not determine whether the occipital condyle is single or double and in which the parasphenoid is in doubt, we can say that the gap is closed.

Broom and Williston have lately made the suggestion that the relationship between the Pelycosauria of North America and the Therapsida of South Africa is so close that it may be well to revive Cope's old order of Theromorpha to include them; this is, however, a tentative suggestion based on a community of very primitive characters.

And now as to future work. More material, carefully collected, with notes of the exact horizons; a careful study of the beds, to determine as far as possible the conditions under which the animals developed and the factors which controlled their evolution; finally, an effort to make out the lines of migrations. The problems are broader than pure morphology. The highly specialized amphibians and reptiles must have lived under very restricted conditions, and as we find the Pelycosaurs, for instance, from Texas across the United States and into Prince Edward Island, and even as far as Bohemia, we may go far toward restoring the condition of large areas when we have a good idea of their habits. The true age of the so-called Permian deposits will also be settled by a closer knowledge. It has been shown that there are no vertebrates in the Texas beds which will prove their Permian age. The fossils from the vicinity of Pittsburgh, discovered several years ago by Raymond, are certainly from the Pennsylvanian. Last summer a specimen of *Spirifer rockymontanus* was discovered either in or close above beds carrying Permian (?) vertebrates in El Cobre Canyon, in New Mexico. It is evident that the position of these vertebrates and amphibians of the end of the Paleozoic has been placed rather higher than there is warrant. Their exact position is yet to be fixed.

Further, when these studies can be extended to include the beds and the fossils of the deposits of the closing Paleozoic all over the world, it will be possible to determine the effect of climate on the development, notably the great glaciation of the southern hemisphere, and we can test Broom's suggestion that the reptiles, at least, originated in the north central portion of South America and from thence spread over the world.

The peculiarities of the fauna, the promise of abundant material, the possibility of making definite determination as to the climate and the conditions of deposition, give us a splendid chance to work out the laws governing the development of groups which have completed their cycle. The laws of decadence, even to extinction, will be as clearly illustrated as the laws of progressive development to an optimum, such as we can see in other and more recent groups.

JURASSIC DINOSAURS

BY W. J. HOLLAND

Without entering into the merits of the discussion which has long been pending as to the geological age of the Wealden, the Potomac beds, and other measures which are claimed by some as being Jurassic, by others as belonging to the Cretaceous, I may state that there appears to me to be reason to strongly maintain, as has been done by Professor Marsh and others, that the formations known in America as the Morrison beds and as the Como, or Atlantosaurus beds, are truly referable to the Jurassic. The discovery by Mr. J. B. Hatcher at Cañon City of the sauropod dinosaur, to which he gave the name of *Haplacanthosaurus*, and which is so closely related to the *Cetiosaurus* of Owen, coming from the Oxford clays, as to be scarcely distinguishable from it, seems to establish beyond question the fact that the beds at Cañon City are Jurassic. Associated with the remains of *Haplacanthosaurus* were found the remains of *Diplodocus, Morosaurus*, and *Stegosaurus*. Now, while the horizons explored by Marsh and Hatcher at Cañon City are probably a little lower than the Morrison or the Como beds, nevertheless the existence in these latter formations of the identical genera, and apparently the same species, indicates very clearly that these beds also are referable to the Jurassic, coming very near to the top of the series, being overlaid in Wyoming, in Colorado, and in Utah by the Dakota sandstones of the Cretaceous. The strata revealed in the quarry in Uinta County, Utah, which has been worked by the Carnegie Museum during the past three years, show relationships to the measures above and below them, coinciding exactly with what we find

in the Como beds in Wyoming. We have the same succession in both localities of marine beds containing belemnites, followed by fluviatile or estuarine beds, composed of compacted sand, gravel, and clays, containing the remains of *Brontosaurus, Diplodocus, Stegosaurus,* and other dinosaurs, both carnivorous and herbivorous. Immediately above these estuarine deposits the Cretaceous reveals itself. If similarity in the physical structure of deposits and the presence in them of the same genera and species prove anything, it is undoubtedly true that the beds which have been recently exploited in Utah were synchronous in their development with the Como beds of Wyoming, and that they therefore belong to the Jurassic.

After this passing reference to the stratigraphy of these formations, I desire to speak briefly of the numerous discoveries throwing light on the Dinosauria which have occurred within the last ten or twelve years. During this time large collections have been made by the American Museum of Natural History, the Field Museum in Chicago, and the Carnegie Museum in Pittsburgh. The collections in the Peabody Museum at Yale and in the United States National Museum at Washington have been made accessible to students and have received careful study by competent investigators. The material at Yale was mainly collected by the late Prof. O. C. Marsh, as was that in Washington. The more recent additions to the splendid collection in the American Museum of Natural History, which is enriched by the possession of the great collection of Professor Cope, have been principally taken from the Como beds, at a locality to which Prof. Henry Fairfield Osborn has given the name of the "Bone Cabin Quarry." The collections from Wyoming in the Carnegie Museum were derived from a locality about 13 miles north of the quarry exploited by the American Museum of Natural History; from the quarry at Cañon City, Colorado, originally opened by Professor Marsh and then abandoned, but reopened and worked for two years under the direction of Prof. J. B. Hatcher, and from a very extensive quarry opened in 1909 in Uinta County, Utah, by Mr. Earl Douglass, under the direction of the writer. The collections in the Field Museum obtained by Professor Riggs represent explorations made by him in western Colorado and in eastern Wyoming.

The result of the acquisition of these collections by the institutions named, as well as the study of the older collections, has been a great advance in our knowledge of the osteological structure of the sauropod dinosaurs.

Professor Osborn's paper, published in the year 1899, on the pelvis and caudal vertebræ of *Diplodocus,* was followed in the year 1901 by a paper

from the pen of the late Prof. John B. Hatcher, giving a restoration of the entire skeleton of *Diplodocus,* subsequently supplemented by a paper by the present writer, in which attention was called to certain anatomical details not previously known.

At this point I desire to call attention to the fact that the remarkable prolongation of the tail of *Diplodocus* has been by the recent discoveries in Utah conclusively shown to be a feature possessed also by other sauropod genera. The Carnegie Museum has recovered almost the entire skeleton of a *Brontosaurus* (?), exceeding in size the largest specimen obtained by Prof. O. C. Marsh. In this lately discovered specimen the caudal vertebræ were found in a continuous series, terminating at the distal end in a long series of small vertebræ not more than four inches long and about one-half an inch in diameter. *Brontosaurus,* as well as *Diplodocus,* was provided with what has been called the "whip-tail." Another interesting revelation is the fact that the limb bones of the *Sauropoda* were not solid, as originally maintained by Marsh, but were traversed by a well developed medullary cavity. This fact is beautifully demonstrated in the case of specimens recently obtained from the quarries in Utah.

That the genera representing the Sauropoda were not all discovered through the indefatigable labors of Marsh and Cope has been shown by the recent explorations to which allusion has been made. One of the most remarkable of the new genera is *Brachiosaurus* of Riggs, a huge dinosaur in which the fore limb apparently exceeded the hind limb in length.

Before concluding this necessarily brief reference to the work of American students, allusion should be made to the studies of Doctor Lull and Dr. O. P. Hay, the former of whom has given us a valuable paper on the osteology of *Stegosaurus.*

In Europe there has been more or less activity, and in a review of the work of the last ten years attention should be called to the installation in the British Museum of a somewhat fragmentary specimen of *Cetiosaurus leedsi* A. S. Woodward, taken from the Oxford clays, which in many important points confirms conclusions reached on this side of the Atlantic as to the structure of the sauropod dinosaurs. Interesting and valuable papers have been published by Baron Nopcsa and others who have investigated Jurassic material. The expedition sent out by the Royal Museum in Berlin under Doctor Janensch to explore the horizons in German East Africa, which had been discovered by Prof. E. Fraas to contain remains of dinosaurs, has already sent back a large mass of material, on which, however, no detailed and formal report has as yet been

published. From the preliminary accounts which have appeared it seems that some at least of this material may be referable to the *Brachiosauridæ* of Riggs. At all events this is the inference the writer draws from published accounts of a very long humerus concerning which much has been written in German periodicals.

The writer will not enter on the discussion which has been going on in reference to the attitude which has been given to certain restorations of the Jurassic dinosaurs both in the old world and in the new, except to say that he is himself more than ever confirmed in the opinion that the crocodilian attitude involves anatomical impossibilities and would be most unnatural to the Sauropoda. He desires in this connection to call attention to the fact that wherever skeletons of sauropods have been found with the limbs articulated and in position the animal to which they belonged has been discovered lying on its side, in the attitude assumed by long-limbed mammals when lying down to die. We have scores of specimens of fossil Crocodilia preserved with their limbs extended and their dorsal vertebræ with the spines pointing vertically upward, but the writer does not believe that in a single instance a sauropod dinosaur has been found in such an attitude, which goes to confirm, in his judgment, the correctness of the opinions hitherto advanced almost without exception by American and European paleontologists, that these animals were capable of walking with the body free from the ground and that they did not crawl.

There has been some discussion as to the life-habits and mode of nutrition of the sauropod dinosaurs, and one or two writers have contended that they were not herbivorous, but that they may have been piscivorous or may have fed on mollusca. There does not appear, however, to be much to support this theory. Had these animals fed extensively on mollusca, it is probable that within the region of the abdominal cavity the remains of shells of ingested mollusca would have been found. In several cases gastroliths have been discovered, but up to the present time there is no evidence that these creatures fed on shell-fish.

In conclusion, it may be said that the field of exploration is still vast and much remains to be discovered as to these extinct forms. The work is expensive, but it is hoped that the generosity of the friends of science will prove equal to the requirements of the case, and that ultimately, as the result of progressive discoveries, we may come to know much more than has as yet been ascertained in reference to the Dinosauria of the Jurassic formations.

CRETACEOUS DINOSAURS

BY RICHARD SWANN LULL

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Introductory

As an anterior time limit I have taken the close of Morrison-Potomac time in the New World and the Wealden, or its equivalent, in the Old, my discussion covering the remainder of the dinosaurian career, whether its final termination were Mesozoic or, as the botanical evidence advanced by Knowlton would seem to indicate, actually in the Tertiary period. The problem can best be discussed by taking the dinosaurian suborders in the following sequence:

Theropoda

Previous to 1901 there had been described from the American Cretaceous a number of genera more or less incompletely known and principally from beds of Senonian age, Judith River and Belly River. Of the forms from the Danian, variously known as Ceratops, Laramie, Hell Creek, or Lance formation, aside from several species of the compsognathoid Ornithomimus, little was known, though the existence of an immense type of the line of Allosaurus was more than suspected. In 1905 Osborn announced the discovery in the Hell Creek beds of two new genera, Tyrannosaurus and Dynamosaurus. In 1906, in a second contribution, Tyrannosaurus was much more fully described, while the name Dynamosaurus was dropped as being separated from the former genus on insufficient grounds. Aside from Tyrannosaurus, the name Albertosaurus was given by Osborn to another "Cretaceous genus of somewhat more primitive character . . . represented in the British Columbia skulls hitherto described as Dryptosaurus." These skulls are from the Edmonton series, which is considered by Barnum Brown to be nearer an equivalent of the Belly River than of the Lance, possibly that of the true Laramie.

The researches of Woodward have extended the recorded geographic range of dinosaurs to the eastward as far as New South Wales, but of this specimen the precise horizon, other than the fact of its being Cretaceous, is not announced.

Of the Cretaceous Theropoda the most interesting recent material has been obtained by the American Museum, where there will be shown anatomically complete restorations of some of the most majestic of the group.

SAUROPODA

In North America the sauropodan career almost ceases with the remarkable host of Morrison forms, for in the Cretaceous beds representatives of this group are extremely rare, but two instances being known to me, both announced within the last ten years. Of these specimens one is mentioned by Gilmore as coming from the Lakota of Buffalo Gap, South Dakota; Gilmore does not, however, identify the remains generically. The other is from an apparently equivalent level, the Trinity sands of Oklahoma, and is identified as Morosaurus. These relics, occurring as they do in a horizon immediately overlying the Morrison, are apparently two of the few remaining representatives of the sauropodan fauna after its general extinction in North America. In Europe, so far as our records now show, this story is practically repeated, for aside from two Aptian localities in France and Portugal, the Cretaceous record above the Wealden is again a blank. Depéret described from Languedoc, France, in beds of Danian age, a supposed sauropod which he called Titanosaurus, and which, if the identification were correct, would indicate a lingering on of these forms in Europe long after their extinction in the New World. Nopcsa, however, has since declared (1910) that this reptile "has nothing to do with the Sauropoda, but belongs to the Trachodont Orthopods." This effectually disposes of what was to me a great quandary at the time of the publication of my paper on dinosaur distribution, in January, 1910, and seems to prove that the extinction of the Sauropoda in the entire northern hemisphere was practically simultaneous.

On the other hand, Cretaceous sauropods are reported from Africa, Madagascar, and India of apparently Cenomanian age, and from Patagonia, where they are found in the Guaranitic beds, which represent the deposition of the very close of the Cretaceous period.

A notable new Cretaceous locality is at Tendaguru, five days' march from Lindi, on the coast of German East Africa, in beds considered by Fraas to be Upper Cretaceous, but which eventually may be shown to

be youngest Lower Cretaceous in age. Here a remarkable deposit of sauropods has been found, the work of collecting now being conducted by Janensch for the Berlin Museum. The most striking species is *Gigantosaurus robustus*, apparently of enormous size, with a humerus 2.10 meters long, ribs 2.50 meters, and a cervical 1.20 meters—bones which seem to show "nearly double dimensions in comparison with Diplodocus." The estimated length of this animal is 35 meters, or nearly 114 feet! The Berlin expedition, which began in 1910, is to be continued through the summer of 1912, and promises most interesting results. Two other types are mentioned, represented by stegosaur-like dorsal spines, the longest a meter in length, and fragments of bone apparently belonging to small iguanodonts. Personally I am skeptical on other grounds of the reference of material from the southern hemisphere to the suborder Orthopoda.

Orthopoda (Predentata)

ORNITHOPODA, IGUANODONTIA

These plant-feeding dinosaurs fall naturally into three groups—unarmored, armored, and horned—all of which survive into the Cretaceous period.

Of these the unarmored Iguanodontia are the most generalized and their evolutionary history the best known. Like the carnivores, they are also divided into a greater and a lesser group. Of the latter during Cretaceous times we know but little, though Brown reports having found one small plant-feeding dinosaur in the Hell Creek beds, the form being as yet undescribed.

Of the Trachodontidæ much has been learned since the mounting of the first individual at the Yale Museum under the direction of Professor Beecher, in 1901. Following this, two fine specimens were mounted in the American Museum, one in standing and the other in feeding posture. The latter was one of the principal specimens of the Cope collection purchased by the American Museum in 1899, and was found by Wortman near the Black Hills of South Dakota in 1882. The erect specimen collected by Brown is from Crooked Creek, in central Montana, while that of Yale is from the classic Converse County locality, and was collected by Hatcher in 1902. Still a fourth individual, a companion to the Yale specimen, is mounted in the National Museum. Impressions of the skin of this animal were already known from material in Washington and from the fragment of a tail collected by Brown. It remained for the veteran collector, Charles H. Sternberg, however, in 1908, to bring to light in Converse County, by aid of his two sons, the most marvelously preserved dinosaur known to science, which seems to have

been an instance of contemporary desiccation before burial. Here the skin is preserved with its complex arrangement of minute scales and entirely bereft of defensive armor, together with portions of the muscles, as well as nearly the entire skeleton, with the exception of the hind feet and tail. This specimen, which was purchased of Mr. Sternberg by the American Museum, is now on exhibition. Another similar specimen, entire except for a small part of the tail and with the skin impression covering a cast of the body, was also found by Sternberg in Converse County in 1910 and sold to the Senckenberg Museum.

In the Old World the most notable discoveries are those of Baron Nopcsa at Siebenbürgen, whence he described in 1899 a new genus and species of Iguanodon-like character known as *Limnosaurus* (now *Telmatosaurus*) *transylvanicus*, and in 1902 and 1904 skull remains of Mochlodon. Nopcsa's paper of 1902 also contains his views on the phylogeny of the Ornithopoda.

STEGOSAURIA

Upon the Stegosauria important progress has been made, not only in the light of new discoveries, but toward the completion of the Stegosauria monograph as well. It seems now very clear that at least two important lines of descent may be traced—one shorter lived, terminating in the tallplated Stegosaurus, the first mounted skeleton of which has recently been erected at Yale; the other culminating in the heavily armored Ankylosaurus described by Brown. The true stegosaurs, like the Sauropoda, culminated in North America in the Morrison.

The ankylosaurs are represented by a number of more or less similar genera, of which the first to be described was Marsh's *Nodosaurus textilis*, from the Pierre, near Como Bluff, Wyoming, of which considerable material now in process of preparation is preserved at Yale. This family in America at least is exclusively confined to the Upper Cretaceous, appearing first in the Niobrara long after the extinction of the aberrant stegosaurs. The ankylosaurs differ from the stegosaurs in the more generalized character of the dermal armor, the median carina of the scutes in the former not having suffered the enormous hypertrophy seen in the stegosaurs. In the ankylosaurs there is a tendency toward the fusion of the scutes into a broad rump shield and into an immense Glyptodon-like tail sheath, the phylum terminating in the most ponderous animated citadel the world has ever seen.

CERATOPSIA

In regard to the Ceratopsia, since the publication of the Ceratopsia monograph in 1908 several new skulls have been brought to light in the

Hell Creek region of Montana and in Converse County, Wyoming, all, however, referable to known species. So far as I am aware, knowledge of but two skeletal elements has been gained since the publication of the monograph—the sternal plates described by Brown and a hyoid element approximately *in situ* in the type specimen of *Triceratops serratus* at Yale, the lower aspect of which has recently been freed from the matrix.

The new material of note has been largely collected by Brown and Sternberg. The greatest need for further exploration seems to be in the Judith River and Edmonton beds, as our knowledge of the more archaic Ceratopsia is still incomplete.

Conclusion

The desiderata include the completion of monographic studies upon the Stegosauria, Theropoda, and Iguanodontia; further evidence to prove or combat Lull's contention that the Orthopoda were exclusively confined to the northern hemisphere and why; and faunal and environmental studies of the successive dinosaurian societies of the Cretaceous. Of recent accessions a notable work is that of Sternberg, who has gone into the apparently exhausted Converse County beds and found at least seven Triceratops skulls and three remarkable Trachodons, two of which still bear the integument. Barnum Brown, who has collected for the American Museum in the Cretaceous beds of Montana and Alberta since 1902, has produced not only admirable results in the amount of material gained, but in the discovery of some of the most remarkable dinosaurs known to science.

The German East African expedition and Baron Nopcsa are further important contributors to our knowledge of Cretaceous life. There is still much to be done, and South America looms large in the gloom of our ignorance as a most promising field for further exploration and research.

CHELONIA

BY OLIVER P. HAY[1]

The writer will endeavor to present here a brief account of the work that has been done during the last ten years on fossil chelonians. The time at his disposal being brief, he fears that a few papers, some important ones possibly, may be overlooked or not treated with entire justice.

[1] Introduced by R. S. Bassler.

The period, especially the first half of it, was one of great activity on the part of students of the extinct species of this interesting group. More than twenty-five authors produced each one or more papers on the subject. In these treatises many new species were described, our knowledge of the structure of many previously named forms increased, and the relationships of the members of the group to one another and to the other orders of reptiles rendered clearer. These communications, furthermore, compel a recognition of the vast amount of discovery and of investigation yet required to place the subject in a satisfactory state.

It has been thought better to discuss the work of the decade chronologically than under the names of authors.

1902

Bloch (1) described and figured an unusually well preserved specimen of *Tropidemys langii* that had been found in the Jurassic quarries near Solothurn. Hay (2) announced a new species *Testudo atascosæ* from the Pleistocene of Texas; also described a nearly complete shell of *Terrapene eurypygia* (Cope). Gaudry (38) expressed his opinion regarding the alveoles in the jaw of the supposed dentated trionychid described by De Stefano. Howes (3), in his address before the section of zoology of the British Association, declared that paleontology had definitely clinched the supposed relationship of the Chelonia to the Plesiosauria. He based his opinion especially on the structure of the shoulder girdle of *Cryptocleidus*. Jaekel described (4) the remarkable reptile *Placochelys placodonta* and expressed the opinion that it threw important light on the phylogeny of the turtles. Lambe (9) reported the occurrence of *Trionyx foveatus* and *T. vagans* in the Cretaceous of Alberta. Reger (49, XXXV) studied the turtles of the Upper Miocene of the tableland of Bavaria and Swabia, listing the species, of which 2 are new. Portis (38) contested De Stefano's interpretation of the alveoles in the supposed dentated trionychid. De Stefano (5) published a paper of 32 pages, with 12 figures, on *Emys cuvieri*. He also described (6) as belonging to a new genus and species a trionychid called *Castresia munieri* from the Eocene of France. In another paper (7) he proposed the new species *Euclastes douvillei*. He announced (8) what he regarded as a new type of trionychid turtle as indicated by a jaw presenting alveoli for teeth. He also (8) described as new *Stylemys bottii*, from probably the Miocene of France. He (5) named and described four new species of Cenozoic turtles. For abstracts of De Stefano's papers the reader may see Geologisches Centralblatt, volume V. Wieland (10) published notes on *Toxochelys* and *Archelon*, and pro-

posed a classification of the marine turtles. Williston (10) figured and described the hinder limb of *Protostega.*

1903

Andrews and Beadnell (11) described the large *Testudo ammon* from the Upper Eocene of Egypt. Andrews (12) reported four other fossil turtles from the Fayûm of Egypt. Dollo (13) described from the Middle Eocene of Belgium *Eochelone brabantica* and discussed the relationships and the phylogeny of the marine turtles. Fraas (14) described and figured *Thalassemys marina* from the Upper Jurassic of Württemberg and expressed his views as to the origin of the turtles. This he found among the Anomodontia. Hay (15) described *Probaëna sculpta* from the Jurassic of Colorado; also (16) two new species of *Clemmys* from the Tertiary of Oregon. Lörenthey (17) announced as new *Trionyx claratomarginatus* and *Euclastes? kochi.* from Hungary. A list of seven Hungarian fossil turtles was presented.

Osborn (24, 43) placed the Testudinata in his subclass Synapsida with the Cotylosauria, Anomodontia, and Sauropterygia. Rabl (18) published observations on the osteology of the turtles and discussed the phylogeny of the group. Von Reinach (19) presented preliminary descriptions of six new species from the Tertiary of Egypt. Later (20) complete descriptions and excellent figures of these were furnished, together with a list of known Egyptian extinct turtles.

Sinclair (16) described *Stylemys calaverensis* from the Quaternary of California. De Stefano continued his researches, describing (5) *Thalassochelys phosphatica* and *Gafsachelys phosphatica* from Tunis, probably of the Eocene; also (5) he defended his views regarding the meaning of the alveoles in the supposed dentated trionychid; also (21) he described the species of *Ptychogaster* found in the Lower Miocene of France, and discussed the position of the genus in the system. He formed for them the family Ptychogasteridæ. Wieland (10) published a note in which he presented a figure of the carapace of *Archelon.*

1904

Andrews (22) published additional descriptions and illustrations of *Testudo ammon*, from the Upper Eocene of Egypt. Boulenger (23), in a classification of the reptiles, derived the turtles from the Plesiosaurian stem. Hay (10) described and figured seven species of fossil turtles belonging to the collection at Yale University. Of these four were new; also (24) announced the discovery of skulls of Trionychidæ

in the Bridger of Wyoming; and (45) presented a description of *Testudo osborniana* from the Miocene of Colorado; also (15) he described *Baëna callosa* from the Judith River beds of Montana. Koch (25) made known *Testudo syrmiensis* from the Pliocene of Hungary. Loomis (10) published the new species *Chrysemys inornata* from the Oligocene of South Dakota. Roger (49, XXXVI) added a few Miocene species to his list of 1902. Wieland (10) discussed the Upper Cretaceous turtles of New Jersey belonging to the genera *Adocus, Osteopygis*, and *Propleura*. Two new species were described and the family Propleuridæ was upheld; later (10) he wrote of the genus *Lytoloma*, and referred *Propleura* to the Propleurinæ, a subfamily of the Cheloniidæ. Williston (26) presented his views regarding the temporal arches of the reptiles.

1905

Case (42) gave an extended account of the osteology of the Diadectidæ, removing the family from the Cotylosauria to the Chelydosauria. He found testudinate characters indicated in the number 18 of presacral vertebræ, in the beginning of a carapace and in the various features of the skull. Hay (27) discussed the structure and relationships of the Amphichelydia, presenting a phylogenetic chart and proposing the new name *Anaphotidemis* for *Chelonides* of *Portis;* later (27) he revised the species of *Toxochelys* and *Porthochelys;* also (27) described a new trionychid *Conchochelys admirabilis* from the Puerco beds of New Mexico. He (24) expressed the view that the turtles had been derived from the Cotylosauria, probably through the Chelydosauria, and not from the Plesiosauria. He (28) dealt in a general way with the turtles of the Bridger Eocene and their environment. Fritsch and Bayer (29) described, with other reptiles and some fishes, three species of turtles from the Cretaceous of Bohemia, among which was the new species *Chelone? regularis*. Hooley (22) announced as new *Nicoria headonensis* from the Headon beds of Hampshire, England. Osborn (24) retained the Testudinata in his subclass Synapsida in close association with the Plesiosauria. Stache (30) described the new Pleurodiran *Sontiochelys cretacea*, from the chalk near Görz. Wieland pursued his studies on the Cretaceous turtles, describing (10) two new species of *Agomphus* from New Jersey and (10) *Toxochelys bauri* from Kansas. He placed *Toxochelys* in the Cheloniidæ. Williston (24) expressed his opinion that the turtles and the plesiosaurs are fundamentally separate groups; also that they are widely removed from the Placodontia, and probably of cotylosaurian origin.

1906

Andrews (44) in a large volume published, among other things, final descriptions and figures of nine turtles from the Fayûm of Egypt. Two of these had not been previously reported. Hay (27) described and figured *Xenochelys formosa* and *Terrapene putnami* and proposed the new genus *Echmatemys;* also (27) gave the characters which distinguish *Chisternon* from *Baëna,* and described more fully *Anosteira.* In another paper (15) he made known five new Miocene species and described a skull of *Stylemys nebrascensis,* all from materials in Carnegie Museum. Lambe (32) described *Testudo exornata* from the Oligocene of Canada and *Baëna pulchra* from the Belly River beds. Later (32) he placed the latter species in the new genus *Boremys* and furnished notes on several other species. Riggs (31) described and figured the new species *Baselemys sinuosa.* Wieland (15) discussed the plastron of *Protostega,* Later (33) he described at length the osteology of *Protostega,* giving special attention to the limbs. He placed the genus in the Cheloniidæ.

1907

Hay (27) described and illustrated seven new species of turtles from the Tertiary of the United States, the most important being, perhaps, a species of *Macrochelys* from the Pliocene or Pleistocene of Florida and a nearly complete skeleton of a trionychid from the Torrejon of New Mexico, *Aspideretes singularis.* Jaekel (47) published a final thesis on *Placochelys,* containing 90 pages, 10 plates, and 50 text figures. To him there appeared to be unmistakable relationships between the turtles and the Placodonts; that both were to be traced back to a common ancestor; and that, especially, the original condition of the turtle shell becomes intelligible through the homologous structures of *Placochelys.*

1908

Hay (34) published his monograph, "The Fossil Turtles of North America." This is a quarto of 568 pages, with 113 plates and 704 text figures. It purports to describe all the species known at the date of publication. The author divided the order into the suborders Athecæ and Thecophora; the latter with the superfamilies Amphichelydia, Pleurodira, Cryptodira, and Trionychoidea. He was inclined to derive the turtles from the Cotylosauria, and more especially the Otocœlidæ. After this was issued another paper was published (35), in which five new species from various levels were described and illustrated; there was also a note on *Glyptops plicatulus.* Moodie (39) declared that the

"relationship between the turtles and the plesiosaurs has therefore been based, in large part, on misconceptions, and the animals do not have the structures on which the greater claims for affinity have rested."

1909

Hay (35) furnished a description and illustration of *Toxochelys stenopora* from a specimen in the U. S. National Museum. The most important parts are the epiplastra and the entoplastron, seen for the first time. Heritsch (36) described and figured the plastron of a young *Trionyx petersi.* In another paper (37) he announced four new species of the same genus from the Tertiary of Steiermark. Loomis (10) announced having found important additional materials of *Testudo arenivaga* Hay and of two new species, *T. brevisterna* and *undabunda,* all from the Harrison beds of Nebraska and Wyoming. Palmer (35) described *Psephophorus calvertensis,* found in the Miocene of Maryland. Wieland (10) revised the group of protostegid turtles. He adopted Baur's superfamily Chelonioidea, and entered under this the Cheloniidæ, Protostegidæ, Desmatochelyidæ, Toxochelyidæ, and Dermatochelyidæ. The new species *Protostega copei* was described. He furnished three plates for the illustration of the great turtle *Archelon ischyros,* mounted at Yale.

1910

Hay (35) furnished descriptions of eight new species of turtles which had been discovered at various places west of the one-hundredth meridian. These are in the U. S. National Museum. *Compsemys* was shown to belong in the superfamily Amphichelydia, and probably with the Baënidæ. Watson (22) referred *Thalassemys rütimeyeri* to the genus *Glyptops.*

1911

Ammon (50) treats of the turtles of the Braunkohlenton of the Upper Miocene of Regensburg, Bavaria, describing and illustrating with excellent figures the new species *Trionyx brunhuberi* and *Clemmys sophiæ.* Broili (46) presented a general account of the Testudinata. Following Siebenrock, 1909, he divided the order into four superfamilies—Cryptodira, Cheloniidea, Pleurodira, and Trionychoidea. The Amphichelydia are included in the Pleurodira and the Dermochelyidæ in the Cheloniidea. Jaekel (Die Wirbelthiere) removed the Testudinata from the true Reptilia and placed them in the Paratheria, a class containing also the Therapsida, the Anomodontia, and the Monotremata. He accepted the group Amphichelydia, erected the sea turtles into a distinct

suborder, and placed therein *Dermochelys*. Knowlton (48) published a paper on the turtles that have been referred to the Judith River beds. He insisted that while 16 species had been credited to the formation, a considerably smaller number have, according to strict evidence, been found there.

The questions most important that have been discussed by students of chelonology are those concerning the origin of the order, the relation of *Dermochelys* to the other sea turtles, and hence the division of the order into suborders. The views of certain authors as to the origin of the Testudinata have been briefly noted above. These animals are regarded as having been derived (*a*) from the Pleisosaurs, (*b*) from the Cotylosaurs, or (*c*) from some Anomodont-like form. Osborn has held that they came from the Cotylosaurs through the Anomodonts. In his "Fossil Turtles of North America" the writer accepted the view that the order here under consideration sprang from the Cotylosaurs, especially from some form like *Otocœlus*, which was supposed to be a Cotylosaur. Williston (40) now declares *Otocœlus* to be an Amphibian. Furthermore, the results of his investigations on the Cotylosaurs make it impossible for the writer to accept any longer the idea that the turtles were derived from them, and he is inclined to betake himself to the camp of the advocates of the Anomodonts.

As regards the origin of the mosaic armor of *Dermochelys*, Wieland (10), who has done excellent work on fossil turtles, has endeavored to fortify his position by referring to certain elements found in *Archelon*. In this genus he found a row of thin plates along the mid-dorsal region overlying the proximal ends of the costal plates and probably concealing the neural plates; also apparently some unusual plates at the outer ends of the ribs. These he regards as elements secondarily acquired, foreshadowing the mosaic of *Dermochelys*. The present writer may possibly be pardoned for briefly discussing Wieland's conclusions. Let it be admitted that those dorsal and marginal plates are present, which, however, is not absolutely proved; are they remnants of a disappearing armor or the beginnings of a new one? Why Wieland accepts the latter opinion is difficult to see, unless he knows that *Archelon* with these elements is the descendant of *Protostega*, which he thinks did not have them. It would constitute a similar case if we were to affirm that the supramarginal horny scutes of *Macrochelys* are a new acquisition, because they are not found in *Chelydra*, so far as we know, an older form. Nor is it certain that the supraneurals were not present in *Protostega*. They were probably present in *P. advena*, and Cope found that the costal plates of *P. gigas* projected so far toward the midline that he thought

that the rib-heads must have articulated with diapophyses. There may have been some supraneurals adhering to these ribs.

Because he found two elements which he thought (and probably correctly) appertained to the dermal keel that belongs above the marginal bones, Wieland concluded that there were seven keels on the carapace, something of a logical leap. Now, in case the skin was thick and leathery and had lost the horny shields, how came it that the keels took accurately the places of the rows of shields, just as they have done also in *Dermochelys*. Again, if the supraneurals of *Toxochelys* were new acquisitions, adumbrating the mosaic of *Dermochelys,* how came it about that they at once effaced themselves by coalescing with the underlying neurals? That is what we might expect from old disappearing structures, but not from new ones destined to play a future important rôle.

As regards the classification, a few remarks may be added, especially on Siebenrock's and Broili's arrangement. The remarks concern the Amphichelydia, which are subordinated to the Pleurodira. However, the skull presents none of the characters peculiar to the Pleurodira, but is like that of the Cryptodira, with sometimes more primitive features. There is no evidence that the animals protected their heads as the Pleurodira do. Any Cryptodire can move its head and neck sidewise. The ilia were not consolidated with the carapace. The pelvis was wholly free from the shell. With the Amphichelydia included, it will be extremely difficult to frame a definition that will separate the Pleurodira from the Cryptodira. That of Dr. Broili certainly does not accomplish this. Furthermore, in case *Carettochelys* is referred to the Trionychoidea, it will be difficult to draw the line between this superfamily and the Cryptodira. The character that is of most value is apparently the lack of contact between the pterygoids.

An opportunity is here presented for some of our systematists to refer *Carettochelys* to that ample category, the "Chelonioidea."

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MARINE REPTILES

BY JOHN C. MERRIAM

During the past ten years important additions to our knowledge of all the great groups of marine reptiles have been made, but in certain of them, as the mosasaurs, which had received especial consideration during the preceding decade, this advance was relatively small.

The contributions which have added most to our knowledge of special groups would seem to the writer to be:

1. The full description and interpretation of the thalattosuchian crocodiles.
2. The additions to our knowledge of the skeletal structure, habits, and relationships of the plesiosaurs.
3. The description and interpretation of the structure of the Triassic, late Jurassic, and Cretaceous ichthyosaurs.
4. The description of a typically marine group of rhynchocephalian or diaptosaurian reptiles.

Of much interest are also the studies of the marine turtles, *Archelon* and *Protostega*, initiated just before the beginning of the past decade; the monographic revision of the marine turtles of America; the discussion of the structure, habits and origin of the mosasaurs; and the description of a new marine reptilian type, the omphalosaurs, which does not as yet seem to find a clearly defined place in our classification scheme of the Reptilia.

Important collections representing marine reptiles have been brought together by many institutions during the past decade, but the value of this material in advancing our knowledge will in many cases not be determined until the completion of studies now in progress. Of the collections which are known to the writer especial importance seems to attach to the splendid plesiosaur and ichthyosaur material from the Oxford Clay which has become the property of the British Museum; the complete plesiosaur specimens obtained from Holzmaden by the Royal Museum of Stuttgart; the extraordinary American plesiosaur material acquired by the University of Kansas; the *Baptanodon* specimens, which have been obtained from the American Jurassic by the University of Wyoming, the Carnegie Museum, and the American Museum; the splendid American mosasaur specimens acquired by the American Museum, the University of Chicago, and the Geological Institute of Tübingen; the collections of ichthyosaur material from the Cretaceous of Germany obtained by the University of Munich; the Triassic ichthyosaur collec-

tions from Spitzbergen secured by the Geological Institute of Upsala; and the collections of Triassic ichthyosaurian, thallatosaurian, and omphalosaurian remains assembled from California and Nevada by the University of California.

During the past decade the following problems relating to the marine Reptilia have been subjects for general discussion:

1. Adaptation and affinities of the Thalattosuchia—Now known to be typical aquatic forms, but not entirely limited to high seas.

2. Relation of Pasasuchia to true Crocodilia—Pasasuchians separated as a distinct order.

3. Origin of the Mosasauria and habitat of young forms—Views as to derivation from a Varanus-like form of Lower Cretaceous age more fully expressed than previously. General absence of specimens representing young suggest that they possibly lived in fresh water.

4. Relationships of the order Ichthyosauria—Suggestions as to relationship to Rhynchocephalia, to Pasachusia, to Cotylosauria, and to Proganosauria. View that the ichthyosaurs originally had a lateral temporal fenestra seems not supported by evidence of the Middle Triassic forms. No clearly defined theory as to origin of this group has been worked out. Probably an old order near Cotylosauria, and has many points in common with the proganosaurs.

5. The origin and course of evolution of the marine turtles, and particularly the course of evolution of the Recent Dermochelyidæ.—Extremely varied opinions as to origin of the leatherback turtles have been expressed. The questions involved have a very important relation to the problem of origin and evolution of the Testudinata.

Of the numerous lines of investigation in the study of marine reptiles now open to us, the following seem to promise important results:

1. A thorough search in all known marine deposits of Lower Triassic age for ancestral forms of the ichthyosaurs and omphalosaurs.

2. Extensive search for marine reptilian remains in the Middle and Upper Triassic of Europe, coupled with an exhaustive comparative study of the collections of marine Triassic forms in all of the European museums.

3. Exploration of marine Mesozoic formations in Asia, with special reference to obtaining material representing early forms of the Ichthyosauria, Plesiosauria, and Mosasauria.

4. An exhaustive examination of the evidence obtained from a study of the history of marine Reptilia with particular reference to its bearing upon the problem of cause and process in evolution.

In a study of the marine reptiles we are necessarily concerned with

many problems relating to the morphology, relationships, geologic range, geographic range, probable habits, and ecological relations of each member of each group. One phase of any problem for any member of a group may well furnish a profitable subject for exhaustive investigation, but the ultimate biological value of all such work depends largely upon the extent to which it assists in an understanding of the processes involved in the evolution of the organic world, and through this means helps to interpret life in the broad sense. Viewed in this light, the marine reptiles, together with the marine mammals, without regard to their position in the scheme of classification, furnish a problem of peculiar interest, which seems to the writer to be one of the large questions still before us for solution. By reason of the peculiar environment in which marine forms of all ages and all quarters of the earth's surface have lived, the problem of their evolution is more sharply defined than in most groups, and therefore perhaps more easily investigated.

The significance of the changes which have taken place in the history of the marine reptiles and mammals has been held by some to be relatively slight in so far as the probability of their throwing light on the problem of cause or mode of evolution is concerned, as the possibilities of change or modification are narrowed in these forms by reason of the peculiar environment. If the influence of selection be considered a factor, it could work only in one direction, if worked at all. To some, natural selection unaided does not seem in any way competent to account for the rapid evolution through numerous stages shown by these reptiles; and the influence of the environment either through the direction of mutations or through directing the mode of use of organs, and therefore possibly the development of the animal, has been considered responsible to a large extent for the tendency and extent of modification.

The question whether the peculiar problem of aquatic adaptation, especially as presented by the reptiles and mammals, is to aid us particularly in an understanding of evolutionary processes, and whether these paleontologic series are by reason of the peculiar limitations of environment especially significant, is yet to be definitely determined. We need first of all a much fuller understanding of all the living and extinct groups, and, following this, a much more exhaustive historical study of the whole problem than has thus far been undertaken.

PALEOZOIC FISHES

BY BASHFORD DEAN

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Introductory

There are three questions which a summary of the work of the past decade might reasonably answer:

(1) What new forms have been discovered?
(2) What new localities have yielded Paleozoic fishes?
(3) What progress has been made in understanding these fishes themselves, both in structure and relationships?

Discovery of new Forms

The past decade has not recorded the discovery of many new and remarkable fishes. We note, however, the description by Traquair of the anomalous *Gemündina* and *Hunsrückia* from the Devonian of Gemünden. Unfortunately these forms are not well preserved and it is perhaps profitless to discuss them at the present time. On the other hand, the new *Ateleaspis* (Traquair) from the Upper Devonian of Scotland is favorably fossilized and is one of the really significant finds of the past decade. Among Placoderms we record the description of *Protitanichthys* (*Coccosteus* ?), *Dinomylostoma* (Eastman), *Protosteus, Pachyosteus* (Jaekel) among the most important.

In the subclass of sharks no forms of extraordinary interest have been found. We may mention a new Edestid (*Lissoprion* Hay) from Nevada and several cestracionts from the middle West (Eastman).

Dipnoans have been elusive; dental plates of *Synthetodus* (Eastman) from the Devonian of Iowa belong possibly to this group.

No Chimæroids of especial interest have been noted.

Teleostomes have been found in considerable numbers in later Paleozoic horizons, but they are lacking in interest from the larger viewpoint.

New Localities yielding Paleozoic Fishes

The past decade has witnessed the discovery of new localities in various horizons throughout the world. Among the most important are dis-

coveries of Upper Silurian fish faunas in northern France (Leriche), in Australia (Chapman), in Portugal (Priem), and Upper Devonian in Colorado (Eastman).

We record also new fossiliferous localities in classical horizons in Scotland. The beds which have yielded the Upper Silurian fishes, *Thelodus, Lanarkia,* and their kindred, have been traced further afield, and from the new localities novel and better material of these important forms may shortly be forthcoming. In the Upper Devonian of Wildungen an extraordinary fish fauna has been developed, and all ichthyologists will await impatiently the publication of Dr. Jaekel's collected studies upon them. In India, South Africa, Madagascar, and Australia fossiliferous localities have been discovered which yield early Teleostomids; but up to the present time no forms of extraordinary interest are described. Nevertheless we have reason to expect that these localities will provide better results in the next years. So, too, the continued development of the localities in the Scottish Carboniferous (Traquair), Mazon Creek (Eastman), Indiana limestone (Branson), and Albert shales of New Brunswick (Lambe) may be expected soon to yield discoveries of greater significance. Among these we await data both as to morphology and distribution; in the latter regard they may be expected to furnish excellent documents for the better understanding of the earth's history.

The Riddles of the Relationships of Fishes

It is in this field, where most is sought, least is apt to be found. Old localities which bring to light each year hundreds of specimens rarely produce one which shows critical structures. So, too, it is a general experience that new localities must long be worked before really good fossils are forthcoming. Even with aid of the best material, results are sometimes dubious. It is safe to say that the studies of the past decade have not solved even one of the greater problems in the descent of fishes. In fact, in several cases later studies show not merely that earlier results are untenable, but that no safe conclusions in other directions can as yet be drawn. Thus it is in the case of *Palæospondylus.* This small "fish," elaborately studied in the eighteen nineties, is now the theme of a still more laborious study by Sollas, who, on the evidence of serial sections, concludes that the fossil was a selachian. *Palæospondylus* is indeed frail and fugitive to bear the weight of ancestral honors which have been heaped upon it. It has been described heretofore as a fossil lamprey, lungfish, chimæroid, teleostome; it now completes a vicious circle by becoming a shark! The fact is that in such a case we are hardly justified in spending good time on bad material; if the same number of hours

had been spent by each investigator in an effort to collect more and better specimens, we might today have solved the puzzle of this form.

Again: the problem of the Ostracophores stands scarcely less involved today than a decade ago. It is true that the painstaking work of Traquair on *Ateleaspis* indicates (Dollo) that this form is a connecting link between the groups of *Thelodus* and *Cephalaspis;* furthermore, the interesting suggestion has been made (Dollo) that *Drepanaspis* was a blind member of the Ostracophore class, having lived in soft ooze at shallow depths. It was the knowledge of this form, by the way, which led to the determination of the nature of *Psammosteus* (Woodward, Rohon). On the other hand, the puzzle of *Thelodus, Lasanius,* and their kindred is still unsolved. It is a plausible hypothesis that they stand not far from the stock from which sharks descended, and that the plated forms came into being in highly specialized lines. The work of Patten on *Tremataspis* and on *Bothriolepis* in this connection provides us with very important documents for the understanding of, or, more fitly perhaps, a confession of ignorance as to these early forms. Certain it is that we can not place them today in closer relationships with true fishes. On the other hand, we are convinced that the new facts do not demonstrate kinship of these forms to Arachnids. Their peculiarities are better interpreted as tokens of high specialization in a line of forerunning chordates in which, as yet, such structures as gillarches (and consequently true jaws) had not been evolved.

The studies of the past decade on Placoderms have been no more satisfactory in solving the puzzle of the relationships of this group. The structure of head and jaws has again been studied (Hussakof), and again the anomalous characters of the "dentition" emphasized. In this regard they certainly stood wide from the true fishes. In a general way we think it safe to say that the phyletic gap which has separated Placoderms and Pteryichthids tends to become smaller. But here again great divergence exists in the opinions of the most eminent specialists. Eastman, studying the dentition of *Mylostoma,* repeats his belief in the connection of these forms with lungfishes. Regan, on the other hand, is convinced that they are Teleostomes. Jaekel adheres to the view that they are masquerading Chimæroids. The writer has had the good fortune to see the new materials from Wildungen, through Professor Jaekel's kindness, but he is unable to see in them any evidence of this kinship; these "fishes" appear to represent a highly specialized line or series of lines of Arthrodiran evolution, neither more nor less. In this connection a minor puzzle has, we believe, been solved. Dollo shows, what we have already suspected, that *Ptyctodus* is an Arthrodire, and *Rhynchodus,* which is

usually placed with *Chimæroids,* will in all probability take a similar position.

The group of sharks has not yet furnished the all important key to piscine descent. The evidence accumulates (Dean) that Cladoselachian sharks stood near the base of the selachian pedigree; and the preservation of a number of their structures in histological detail shows that the kidney extended far behind the region of the pelvic fins, making it probable, therefore, that the cloaca was subcaudal and that in these forms a portion of the gut was functional which today is retained in shark embryos as post-anal. In the matter of the primitive fin structures of Cladoselachian sharks, we note that Jaekel ascribes pelvic claspers to one of the specimens in the British Museum, but a renewed examination of this slab convinces us that the evidence is unsubstantial. The studies of the past decade have contributed additional ground for believing that Acanthodian sharks were close relatives of Cladoselachids, but more highly specialized (Dean). In some respects, it must be admitted, they retain primitive structures, even more primitive than known today in Cladoselachids. Thus, the curious jointing present in the jaw (Jaekel) indicates a singularly close homology of jaw and branchial arch. Regarding Acanthodians, but in another line, Dollo has made the interesting point that they were planktonivorous fishes; and, solving of a minor puzzle, we have now the data that the Acanthodians included *Gyracanthus* (Traquair and Woodward). Still another smaller problem has been solved (Hay) in the case of *Edestus;* its curious coil of teeth was placed in the symphyseal region, as many believed and as Eastman demonstrated indirectly—that is, on the evidence of *Campyloprion.*

Upon the origin of Dipnoi it is safe to say that no light has been cast during the past decade.

Nor have the puzzles of Chimeroids been solved from the point in view of paleontology. Evidence has indicated that *Menaspis* (Permian) is a primitive Chimæroid (Dean), which approaches very closely certain Deltodont (primitive Cestraciont) sharks. It should here be mentioned that Regan maintains that Chimæroids were derived from still more primitive sharks than early Cestracionts. In any event the findings of paleontology as to selachian derivation receive confirmation on the side of embryology, for the study of Chimæroids points out that their plan of development is like that of sharks, but in numerous directions more specialized.

The past ten years have contributed no major documents to clear up our knowledge of the early Teleostomes. In some cases, it is true, a

marvelously perfect condition of preservation is present in special structures, and is most encouraging to the student who wishes to base his conclusions on something more than scales, teeth, and bones. Thus, in the small ganoid *Rhadinichthys deani* Eastman, from the Lower Carboniferous of Kentucky, one may examine (Parker) "indubitable remains of the actual brain, internal ears, nerve endings and bloodvessels," and from such intimate structures attempt detailed comparisons with modern forms.

MESOZOIC AND CENOZOIC FISHES

BY C. R. EASTMAN

Among the more important general results that have been gained during the last decade from a study of the several piscine faunas occurring throughout the Mesozoic and Cenozoic eras, the following are worthy of attention:

With the advent of the Mesozoic, that is to say, in the early Trias, fishes of a higher grade in the scale of progressive evolution make their appearance than those which were dominant during the Paleozoic. Among Actinopterygian fishes the ancient race of Paleoniscids continues, it is true, but the group is marked by degeneracy in the direction of modern sturgeons, and the incoming Protospondyli of the Trias develop a number of series, which in the fullness of time become molded into the characteristic types of Upper Cretaceous and Tertiary fishes, in the end becoming transformed into our present-day fauna.

These large-mouthed Protospondyli with conical teeth, which are traceable from the Trias onward until they pass almost imperceptibly into modern bony fishes, constitute at least three important families—the Eugnathidæ, Amiidæ, and Pachycormidæ. It is interesting to note that the last mentioned of these is represented in the Alpine Middle Trias by the genus *Urolepis*, which shows considerable resemblance to the Paleoniscids. The Pacycormidæ in particular show distinct evidence of gradual progression as they are traced upward in their geological range.

During the Jurassic the next higher suborder appears, that of the Isospondyli, characterized by a simplified mandible and a more completely ossified internal skeleton. The teleostomes which acquire this new and advanced type of skeletal frame soon give rise to a varied series of families and begin to predominate in the Cretaceous ichthyic fauna. Until this time, as remarked by one of our foremost authorities on paleichthyology, Dr. A. Smith Woodward, "the skull of the Actinopterygii had always been remarkably uniform in type, . . . the pelvic fins

always retained their primitive remote situation, and the fin-rays never became spines. During the Cretaceous period the majority of the bony fishes began to exhibit modifications in all these characters, and the changes occurred so rapidly that, by the dawn of the Eocene period, the diversity observable in the dominant fish fauna was much greater than it had ever been before. At this remote epoch, indeed, nearly all the great groups of bony fishes, as represented in the existing world, were already differentiated, and their subsequent modifications have been of quite a minor character."

The general course of evolution observable among fishes being as above briefly summarized, it has been the aim of specialists during the past decade to work out the details of classification with ever increasing accuracy, as far as the existing state of our knowledge will permit. A further object of study has been to gather more precise information regarding the anatomical structure of the different forms whose remains have been preserved, whether in the entire, or crushed and fragmentary condition; and towards this end a vast deal of material has been accumulated. Still another objective point, and one more difficult of attainment, has been to trace the stages of differentiation passed through by the dominant Tertiary fishes, which in turn gave rise to the modern fauna.

In connection with the latter problem, an interesting allied topic has presented itself for investigation, namely, that of the antiquity of the deep-sea fish fauna. It is now well recognized that among marine organisms many forms which have been worsted in the unceasing struggle for existence—waged always most keenly along the shorelines of continents—manage to survive through having emigrated elsewhere, amid less trying conditions. Divers groups of animals, for instance, have been forced to seek a refuge in fresh waters, and have there continued to persist, some dwindling, others flourishing, according to their ability to react in response to changed environment. Other groups, and among them many fishes, have been driven into tenanting the abysmal depths of the ocean.

Paleontology shows that the last mentioned refuge was not inhabited to any great extent by fishes prior to the latter part of the Cretaceous. But, beginning during this period and steadily proceeding until the present day, a gradual migration of certain groups of fishes into great depths of the ocean has been in progress, coincident with remarkably striking changes in the anatomical structure of the emigrant outcasts. As a result of recent researches, more especially of the late Cretaceous and Eocene deep-sea fish faunas, we are enabled to note the gradually changing constitution of these abyssal assemblages from the close of the

Mesozoic onward to our own day. Mention may be made at this point of at least one specimen of *Dercetis*[1] from the Lebanon Cretaceous which seems to prove that some of these deep-sea fishes were provided with a distensible stomach, as is commonly true of modern forms.

To pass in review the large series of important contributions to the literature of Mesozoic and Cenozoic fishes that has appeared during the past decade would exceed the limits assigned to the present article. Nevertheless a few words may be said concerning the nature of the publications covering these topics. The greater number of memoirs consists of those which take account of the entire assemblage of fossil fishes occurring within certain stratigraphic horizons—that is to say, the subject-matter is treated from the faunistic standpoint, including descriptions of new genera and species. Less in number, but paramount in interest and importance, are the series of papers whose purpose it is to elucidate the structure of particular fossil forms, to inquire into their systematic relations and phylogeny, or to throw light on various matters relating to their environment, distribution, and the like. Among the latter class of contributions may be mentioned, for instance, the papers by Abel[2] and Dollo[3] on extinct flying-fishes, those by Campbell Brown[4] and Ernst Koken[5] on the genus Hybodus, one by Erwin Hennig[6] on Pycnodonts, another by Rudolf Cramer[7] on Eocene species of *Mene*, Bassani's memoir on *Myripristis*,[8] and similar studies by other Italian authors.

A bare enumeration of titles of some of the more important faunistic monographs that have enriched the literature within the last ten years must suffice for the present article. Among memoirs devoted to Triassic fish faunas, those by Bassani, Schellwien, Kramberger, and De-Alessandri[9] are of the highest excellence. In this country the Triassic fish faunas of New Jersey and Connecticut have been reviewed in bulletins published by the State geological surveys of those commonwealths, and the con-

[1] This specimen is figured by A. S. Woodward in Natural Science, 1898, vol. xii, pl. x.

[2] O. Abel: Fossile Flugfische. Verh. deutsch. Zool. Ges., 15ten Vers., 1905, pp. 47-48.

[3] L. Dollo: Les poissons voiliers. Zool. Jahrb., Abth. Syst., 1909, vol. xxvii, pp. 419-438.

[4] C. Brown: Ueber das Genus Hybodus und seine systematische Stellung. Palæontogr., 1900, vol. xlvi, pp. 149-175.

[5] E. Koken: Ueber Hybodus. Geol. Palæont. Abhandl., 1907, n. s., vol. v, pp. 1-18.

[6] E. Hennig: Gyrodus und die Organisation der Pyknodonten. Palæontogr., 1906, vol. liii, pp. 137-208.

[7] R. Cramer: *Mene rhombeus* (Volta). Zeitschr. deutsch. geol. Ges., 1906, vol. lviii.

[8] F. Bassani: Sopra un Bericide del calcare miocenico di Lecce, etc. Atti della R. Accad. Scienze di Napoli, 1911, vol. xv, pp. 1-15.

[9] G. De-Alessandri: Studii sui pesci triasici della Lombardia. Mem. Soc. Ital. Sci. Nat., 1910, vol. vii, pp. 1-147.

temporary faunas of the Pacific slope have been treated in publications of the University of California. Turning to the African continent, the writings of Dr. Broom[10] and others have enlightened us with regard to the fossil fishes of the Upper Karroo beds.

Jurassic fishes have continued to receive attention during the past decade, though for the most part in the form of short papers, like those of Dr. A. Smith Woodward and others in England. A notable contribution on the fauna of the lithographic limestone of Bavaria is that by Dr. Erich Heineke.[11] Reference may be made in this connection to Dr. Walther's interesting discussion of the Solenhofen fauna, to be found in the anniversary volume in honor of Professor Ernst Haeckel.

The Wealden fishes of Belgium have recently been studied by the veteran Scottish ichthyologist, Dr. R. H. Traquair.[12] Of the first order of importance is the splendid monograph on British Cretaceous Fishes, by Dr. A. S. Woodward, published by the Palæontographical Society. To the same author students are indebted for a number of illuminating papers on the Cretaceous fishes of Lebanon and other localities, as well as for the concluding volume of that most indispensable of all works on the subject of fossil fishes, the Catalogue of the British Museum (vol. iv, 1901). The researches of Professor F. Priem, of Paris, have extended not only over the Cretaceous fish faunas of France, northern Africa, and Persia (1908), but we are indebted to him and to Dr. Maurice Leriche, of Lille, for a revision of the extensive Tertiary fish faunas of Franco-Belgian territory. In this country the only recent publication on Cretaceous fishes is contained in Bulletin 4 of the Geological Survey of New Jersey, the full title of the paper being "A Description of the Fossil Fish Remains of the Cretaceous, Eocene and Miocene Formations of New Jersey," by Henry W. Fowler (1911).

The recent literature of Tertiary fishes is not very extensive, the principal memoirs being those by Priem and Leriche, already referred to. The Eocene fish fauna of Monte Bolca, in northern Italy, has received renewed attention on the part of several writers, one of the memoirs dealing with the type specimens in the Paris Museum; and several contributions have appeared on the Tertiary fishes of northern Africa (Priem, Stromer), Australia (Chapman), and South America (Woodward, Sangiorgi, De-Alessandri). In this country, the Eocene

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[10] R. Broom: The fossil fishes of the Upper Karroo Beds of South Africa. Ann. South African Mus., 1901, vol. 7, pp. 251-269.

[11] E. Heineke: Die Ganoiden und Teleostier des lithographischen Schiefers von Nusplingen. Geol. Pal. Abhandl., 1907, vol. xii, pp. 159-214.

[12] Les poissons wealdiens de Bernissart. Mém. Mus. Roy. d'Hist. Nat. Belg., 1911 (Année 1910), vol. vi, pp. 1-65.

and Miocene fish faunas of Maryland and New Jersey have been described in reports published by the geological surveys of these States, and several minor contributions have appeared on Tertiary fishes from the western States, more especially Colorado, Nevada, and California. Most recently of all, President D. S. Jordan[13] has described an interesting collection of fish remains from presumably Lower Eocene deposits of Bahia, Brazil, thus supplementing his earlier studies in conjunction with Professor Branner upon the Cretaceous Fishes of the Province of Cearà, Brazil (1908). During the year just closed, also, fresh discoveries of Tertiary fishes have been reported from Kamerun, from near Benito, in the French Congo, and elsewhere on the west coast of equatorial Africa.

CORRELATION AND PALEOGEOGRAPHY[1]

BY HENRY FAIRFIELD OSBORN

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Introductory

Correlation and paleogeography[2] are the sister offspring of geology and paleontology; correlation is, therefore, at once paleontologic and geologic; paleogeography should be based on both paleobotany and vertebrate and invertebrate paleontology, or past biotas, or faunas or floras, studied conjointly with all the geologic data available.

A narrow perspective, absolutely certain to lead to temporary or incon-

[13] D. S. Jordan: Description of a collection of Fossil Fishes from the Bituminous Shales at Riacho Doce, State of Alagôas, Brazil. Annals Carnegie Museum, 1911, vol. vii, No. 2.

[1] Address before the Paleontological Society, December 29, 1911. Special appropriations have been made from the Bache Fund of the National Academy of Sciences for the prosecution of research in correlation.

[2] See bibliography, 1900-1912, on pages 254-256.

clusive results, is that which bases generalizations on plants or animals, or earth conditions singly, instead of grouping and synthesizing all possible evidence from all three sources. Plants, invertebrates, and vertebrates each give their own peculiar testimony. A synthesis of this broad nature

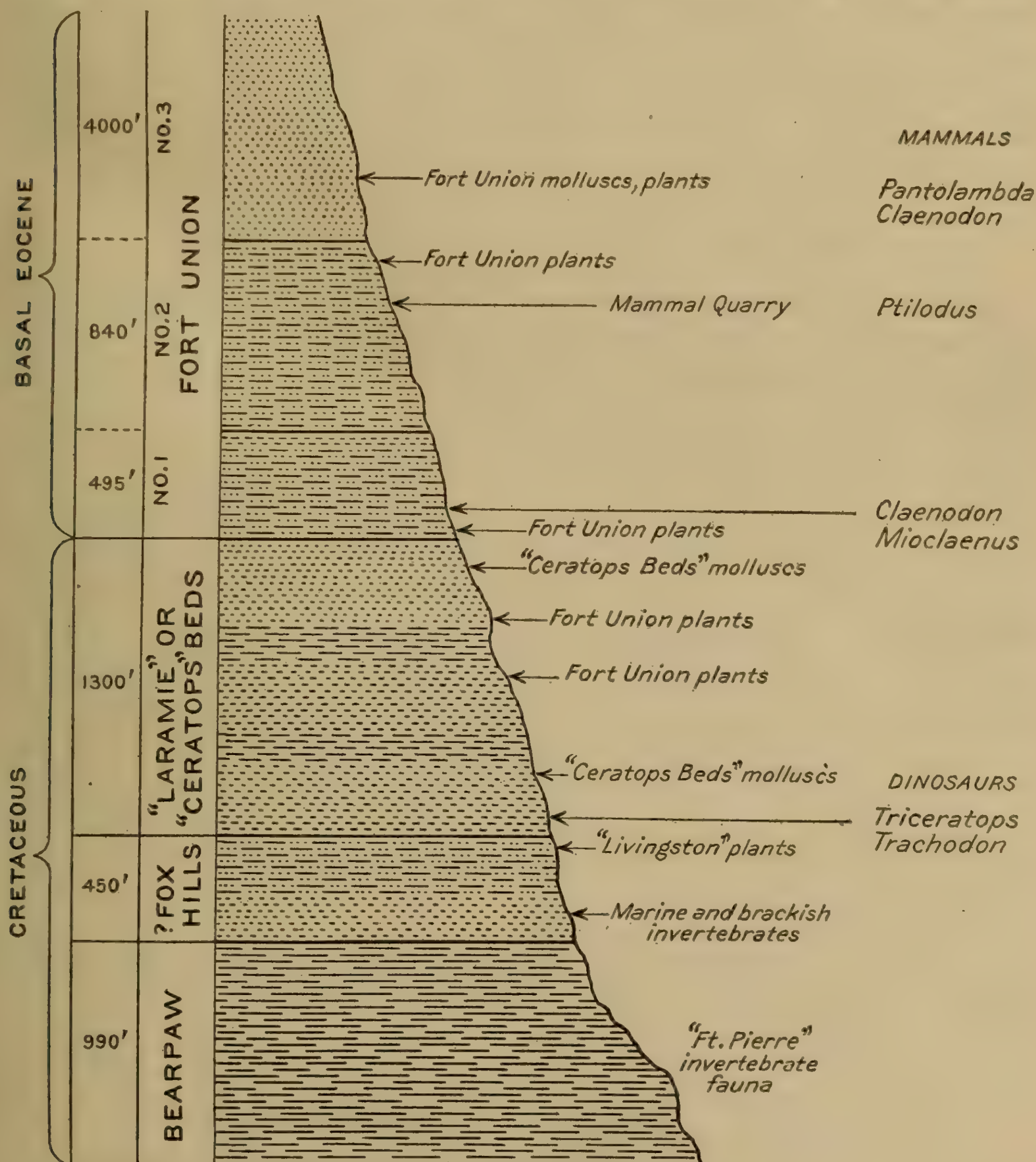

FIGURE 1.—*Section from Hell Creek, Montana*
Transition from Summit of Cretaceous to Basal Eocene. Modified after Brown
Upper: *Pantolambda* Zone, Fort Union
Lower: *Triceratops* Zone, "Laramie"

is what is demanded both for correlation and for paleogeographic conclusions, which depend so largely on synthetic correlation.

Granting that the above represent the modern canons for correlation and paleogeography, in the brief time allotted our discussion must be confined to the progress of the past ten years, based chiefly on the mammals

of the Tertiary epoch and the formations which contain them in North America. Such correlation between horizons and countries where mammals alone are found has certain peculiar advantages: first, that the trend and rate of development is fairly uniform the world over; second, that large faunal communities in similar stages of development generally imply geographic intercourse; third, that the cycles of physiographic and climatic change are broadly similar in the two halves of the northern hemisphere; fourth, that faunal community implies land connections and geographic continuity or continuity of migration areas.

General Contributors of the past Decade

Among the general contributors of the past decade to correlation and migration in the northern hemisphere are the following: Matthew (1906, 1908),[3] Osborn (1900, 1909, 1910),[4] Weeks (1902),[5] Wortman (1903).[6]

Correlation of American Tertiaries

Marsh and Cope treated the great formations of the American Eocene as units, even where 1,000 to 2,000 feet in thickness. The greatest progress which has been made in the past decade is due to the breaking up of these formational units into sub-units, or life zones, usually marked off more or less clearly, by geologic discontinuity. This splitting up of the formations has been accompanied by new standards of precision in recording the succession of mutations and of species on certain levels which have

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[3] W. D. Matthew: Hypothetical Outlines of the Continents in Tertiary times. Bulletin of the American Museum of Natural History, vol. xxii, art. xxi, October 25, 1906, pp. 353-384.

Mammalian Migrations between Europe and North America. American Journal of Science, vol. xxv, January, 1908, pp. 68-70.

[4] H. F. Osborn: The Geological and Faunal Relations of Europe and America during the Tertiary Period and the Theory of the Successive Invasions of an African Fauna. Science, n. s., vol. xi, no. 276, April 13, 1900, pp. 561-574.

Correlation between Tertiary Mammal Horizons of Europe and America. An introduction to the more exact Investigations of Tertiary Zoogeography. Preliminary study, with third trial sheet. Annals of the New York Academy of Science, vol. 13, no. 1, July 21, 1900, pp. 1-72.

Cenozoic Mammal Horizons of Western North America, with Faunal Lists of the Tertiary Mammalia of the West, by W. D. Matthew. Publications of the U. S. Geological Survey, Bulletin No. 361.

The Paleontologic Correlation through the Bache Fund. Science, n. s., vol. xxxi, no. 794, March 18, 1910, pp. 407-408.

Correlation of the Cenozoic through its Mammalian Life. Journal of Geology, vol. xviii, no. 3, April-May, 1910, pp. 201-215. Outlines of geologic history, 8vo, Chicago University Press, July 10, 1910, pp. 251-264.

The Age of Mammals in Europe, Asia, and North America. 8vo, The Macmillan Company, New York, October 25, 1910, pp. 635.

[5] F. B. Weeks: North American Geologic Formation Names. Bibliography, Synonym, and Distribution. Bulletin of the U. S. Geological Survey, no. 191, 1902.

[6] J. L. Wortman: Origin of the Primates. American Journal of Science [4], xv, June, 1903.

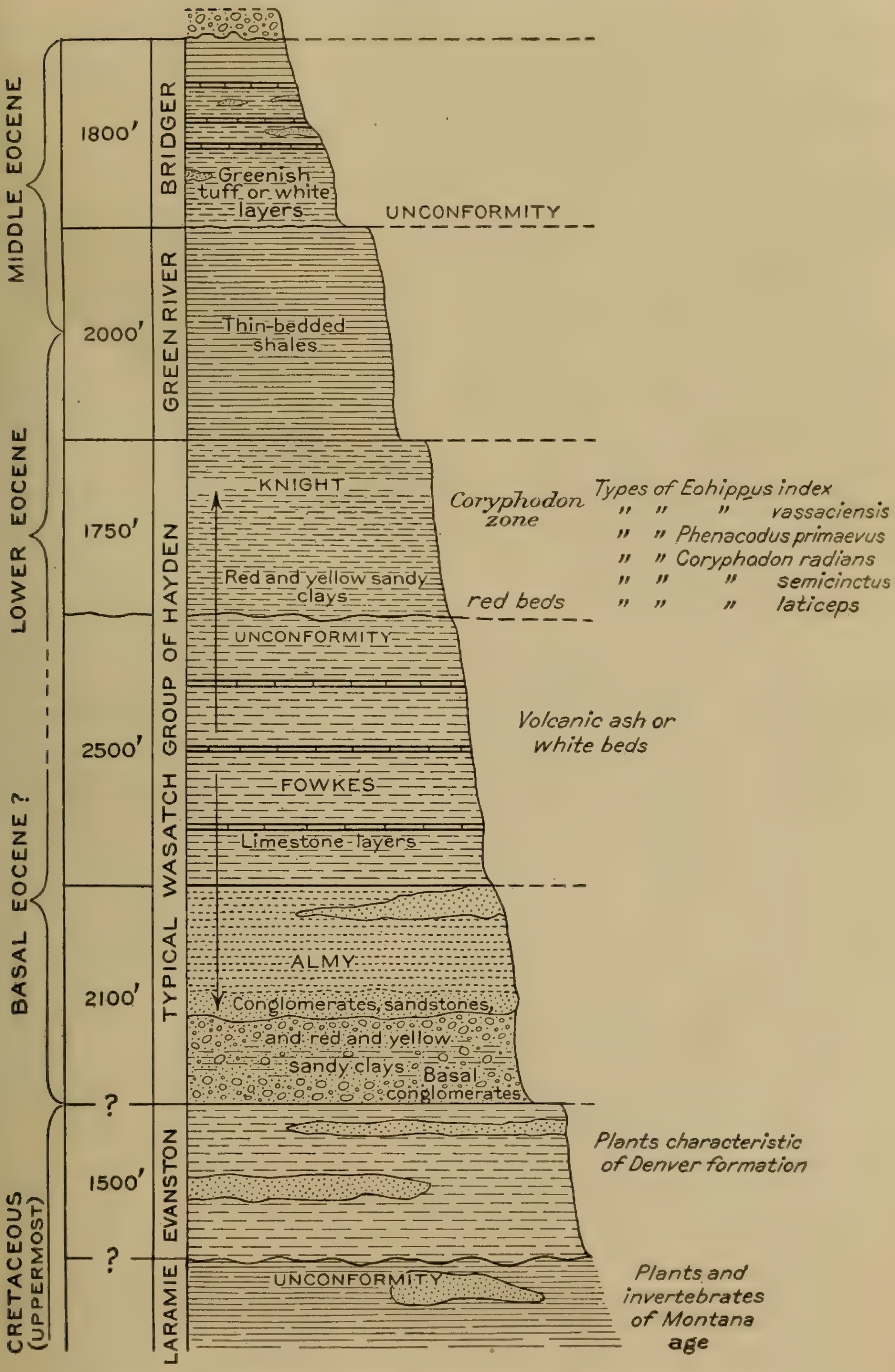

FIGURE 2.—*Composite Section, Cretaceous to Lower Eocene Series*

Typical Wasatch of southwestern Wyoming

Upper: *Orohippus* and *Uintatherium* Zone, Bridger
Middle: *Coryphodon* Zone, or Knight formation

been established in American work and promise to set new standards for foreign work (see Matthew, 1909,[7] Osborn, 1907).[8] These standards have been developed independently, but are quite similar to those long in use by invertebrate paleontologists. The subdivision of the old units into

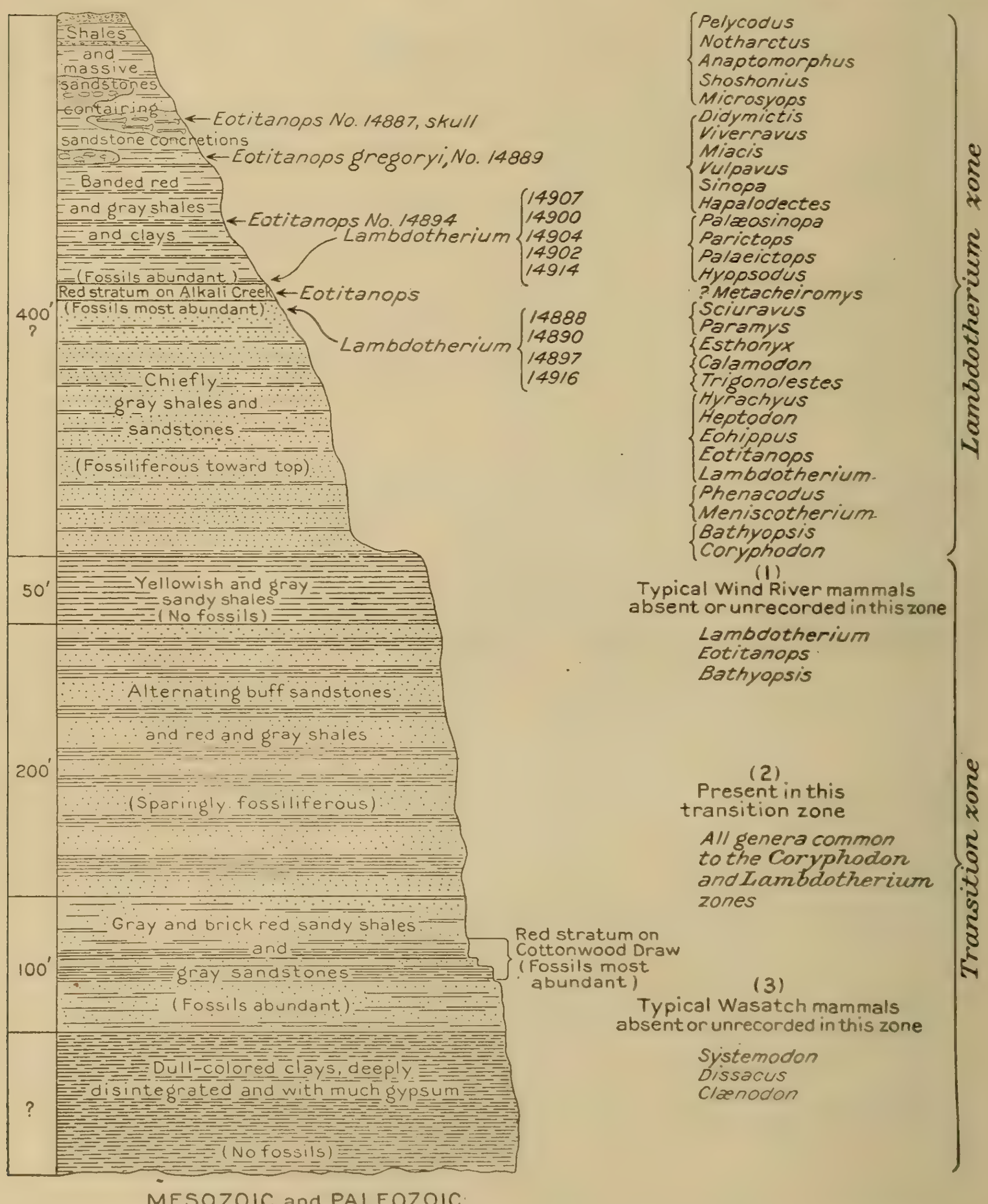

FIGURE 3.—*Generalized Section—Typical Wind River Series of western Wyoming*

(After Granger and Sinclair)

Upper: *Lambdotherium* Zone, Lost Cabin

Middle: Transition Zone, Lysite

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[7] W. D. Matthew: A Provisional Classification of the Fresh-water Tertiary of the West. Bulletin of the American Museum of Natural History, vol. 12, pp. 19-75.

[8] H. F. Osborn: Tertiary Mammal Horizons of North America. Bulletin of the American Museum of Natural History, vol. xxiii, art. xi, March 30, 1907, pp. 237-254.

several levels of mammalian life zones enables us to institute exact comparisons with other life zones.

Middle and Upper Eocene

The first formation to be analyzed in this way was the classic Bridger of southwestern Wyoming, a pivotal formation in the Middle Eocene. Under the instruction of the writer, the American Museum parties, guided by Matthew and Granger, especially undertook the problem of ascertaining whether the Bridger was divisible into a series of life zones. After four years (1902-1905) of very careful geologic work on the ground, accompanied by the level-record of every specimen, the work reached a highly successful conclusion.[9]

The Bridger was found to subdivide geologically and faunistically into five levels, designated as A, B, C, D, E. Of these levels A, B form the Lower Bridger, characterized by the absence of *Uintatherium*, and C, D, and E the Upper Bridger, distinguished by the sudden appearance of *Uintatherium*, a genus so characteristic as to give the distinctive zonal name (see table, page 240).

The next problem was to correlate the Washakie formation, lying 50 miles east of the Bridger. This, by careful lithological and paleontological analysis by Granger and Matthew, was found to split into Washakie A, identical in its mammalian life with Bridger D, and Washakie B presenting a higher life zone, containing *Eobasileus* and *Dolichorhinus*. The Washakie formation (Granger, 1909)[10] was found to couple in a precise and beautiful manner the Bridger and Uinta formations, as shown in the accompanying diagram.

Uinta.	Washakie.	Bridger.	Life Zones.
C. Upper.			Diplacodon.
B. Middle.	B. Upper		Eobasileus.
	A. Lower.	Upper D. C.	Uintatherium.
		Lower B. A.	Orohippus.
			Formations.

[9] See Matthew: Carnivora and Insectivora of the Bridger Basin, Middle Eocene. Memoirs of the American Museum of Natural History, vol. ix, August, 1909, pp. 291-561.

[10] Walter Granger: Faunal Horizons of the Washakie Formation of Southern Wyoming. Bulletin of the American Museum of Natural History, vol. xxvi, art. iii, January 19, 1909, pp. 13-23.

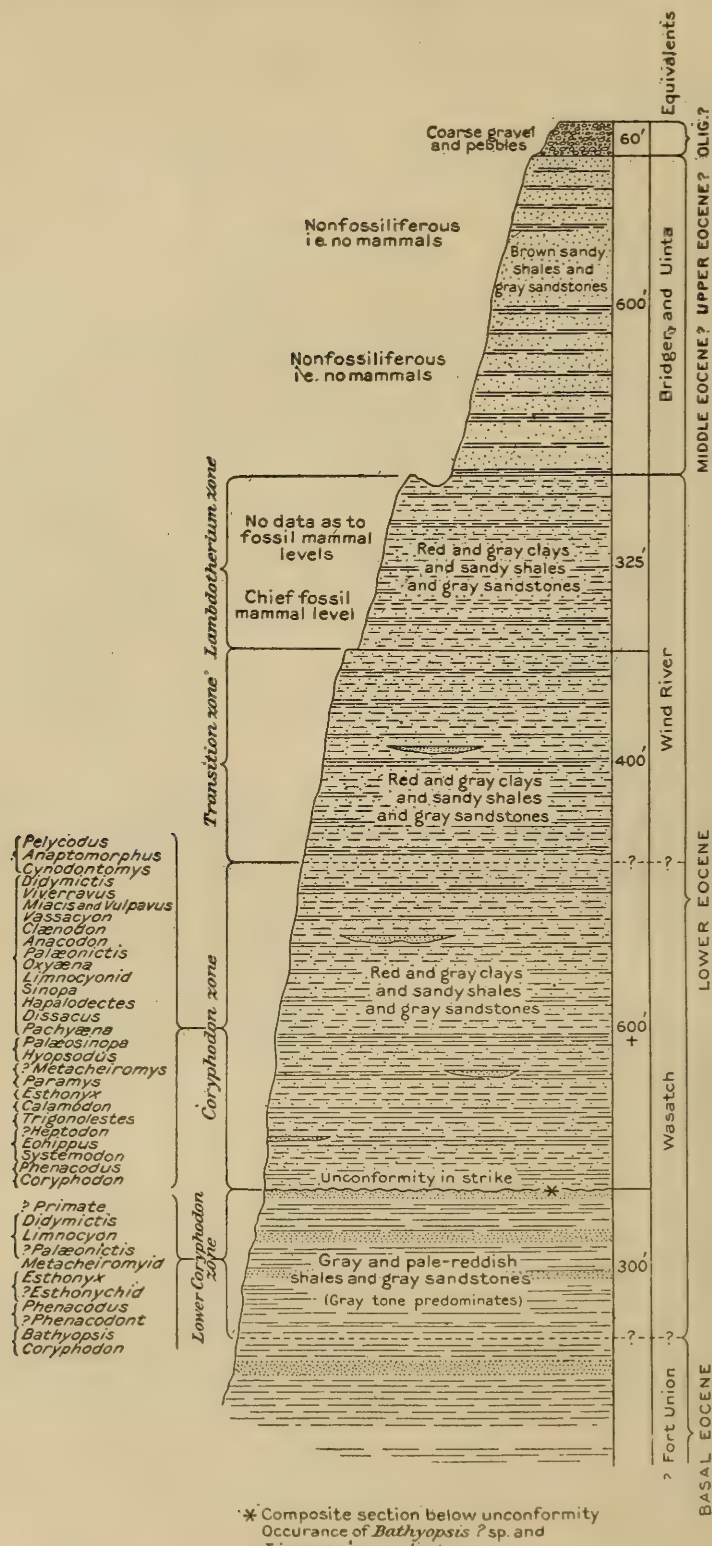

FIGURE 4.—*Generalized Section—Lower Eocene of Big Horn Basin, western Wyoming*

(After Granger and Sinclair)

Upper: *Lambdotherium* Zone, "Wind River"
Middle: Transition Zone, "Lysite"
Lower: *Coryphodon* Zone, "Knight"
Lower: Lower *Coryphodon* Zone, "Ralston"

A closer homotaxis could hardly be found than that existing between the Lower Washakie and Upper Bridger. That the Upper Washakie similarly was laid down synchronously with the Middle Uinta is demonstrated by the common presence of a rich *Dolichorhinus* fauna characterized by these very peculiar long-skulled titanotheres.

The above diagram shows the connecting system which has enabled us step by step to correlate not only the Bridger, Washakie, and Uinta, but all the formations of our wonderful American Eocene deposits except those at the very base of the Eocene or summit of the Cretaceous, which still await further analysis.

Our knowledge of the fluviatile Uinta B, or *Dolichorhinus-Eobasileus* zone fauna, first made known through the discoveries of Peterson in 1894, has been greatly enriched by the more recent explorations of Douglas for the Carnegie Museum and of Riggs for the Field Museum, so that this life zone becomes one of the best known of the Rocky Mountain series. The overlying Uinta C, first explored by Marsh in 1871, is characterized by the presence of the large, well horned titanotheres (*e. g., Protitanotherium superbum*), and we may confidently anticipate that through further exploration exact correlation will be established between this *Protitanotherium* and *Diplacodon* zone and some of the basal formations of the White River Oligocene of the great Badlands of South Dakota. Thus the top of the Eocene will be neatly articulated with the base of the Oligocene.

Lower Eocene

Working downward from the Middle Eocene of the Bridger and pursuing the same methods, Granger and Sinclair[11] have made an exhaustive geologic and faunistic examination of the Wind River and of the Wasatch, supplementing the geologic work of Darton (1906),[13] Veatch (1907) and Fisher (1906).† The exact faunistic touch on the upper levels with the base of the Bridger has not been secured, because (see table, page 244) Bridger A is almost barren and the very summit of the Wind River is also barren; the exposures of the "Wind River Series" of the Beaver Divide, a barren part of which may correlate with the "Bridger."

[11] W. J. Sinclair and Walter Granger: Eocene and Oligocene of the Wind River and Bighorn basins. Bulletin of the American Museum of Natural History, vol. xxx, art. vii, July 11, 1911, pp. 83-117.

[13] N. H. Darton: Geology of the Big Horn Mountains. U. S. Geological Survey, Professional Paper No. 51, 1906.

†Fisher, Cassius A.: "Geology and Water Resources of the Bighorn Basin, Wyoming." U. S. Geological Survey, Professional Paper 53, 1906.

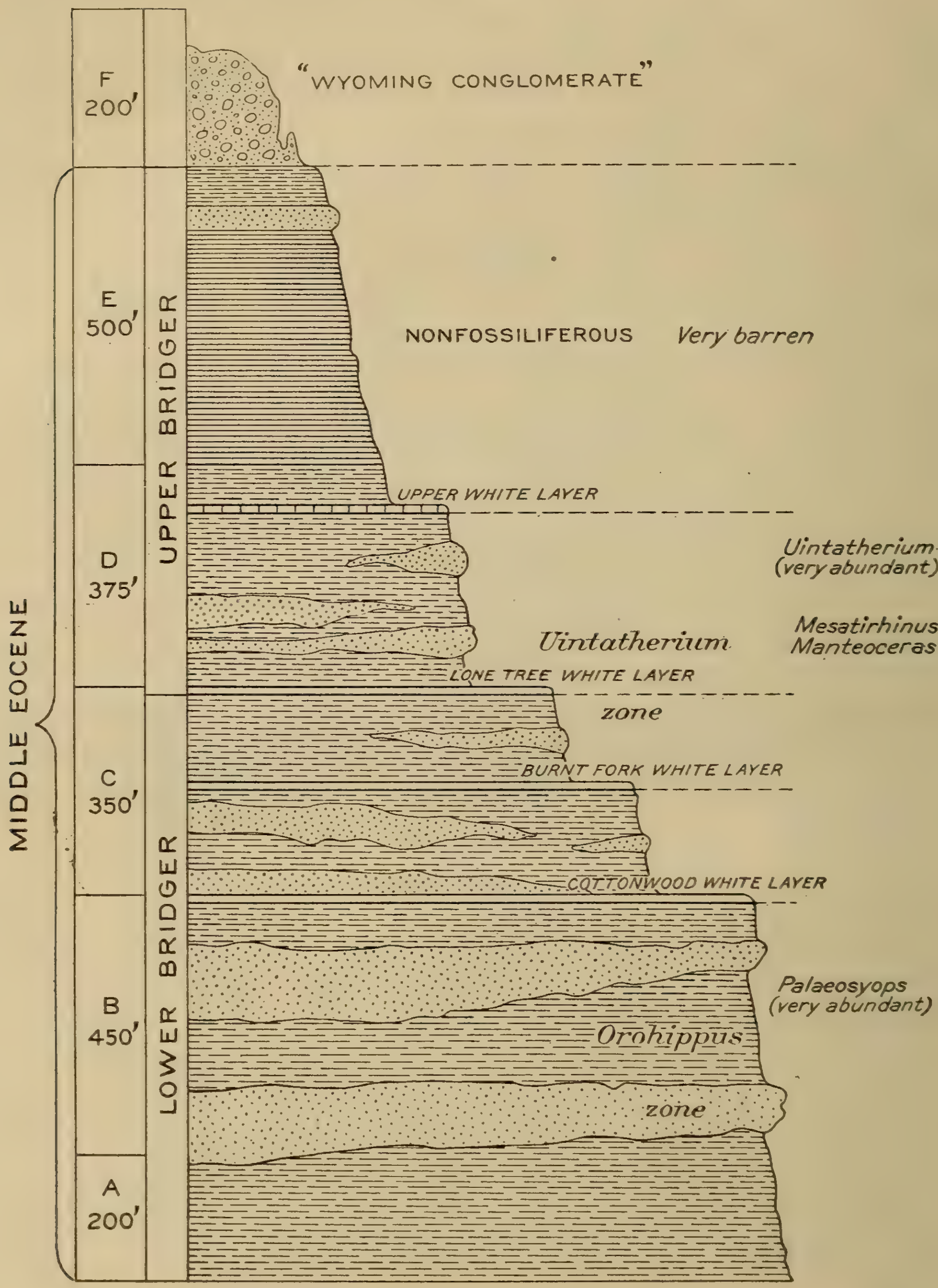

FIGURE 5.—*Generalized Section—Middle Eocene, typical Bridger Series*

(After Matthew and Granger)

Upper: ? Zone
Middle: *Uintatherium* Zone
Lower: *Orohippus* Zone

Attention may be called at this point to the practice of distinguishing between typical series like the Bridger, Wind River, and Wasatch (see Veatch, 1907),[12] and correlated series, which may be distinguished by quotation marks as "Bridger," "Wind River," "Wasatch," etcetera. Life zonal names are applicable throughout.

The lithological or geological characters in this ancient fluviatile, flood-plain, and partly lacustrine country are limited in uniformity. Correlation by geologic characters would be absolutely impossible. There are some cases, however, where geologic similarity helps us; for

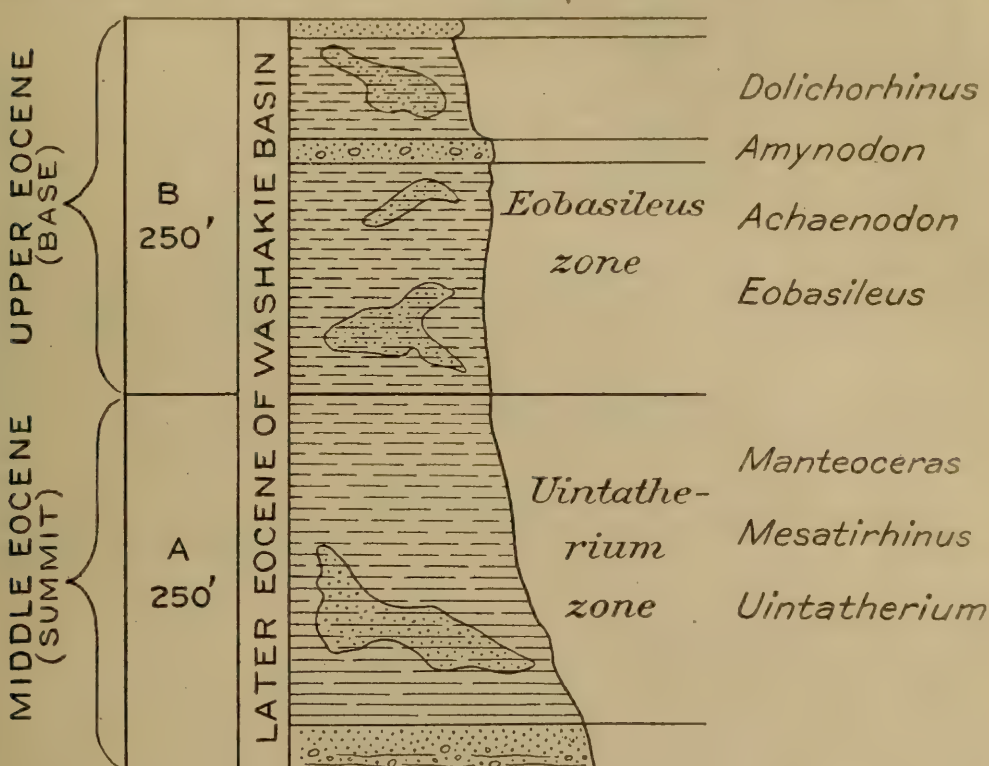

FIGURE 6.—*Middle and Upper Eocene Section—Washakie Series of southern Wyoming*
Upper: *Eobasileus* Zone
Lower: *Uintatherium* Zone

example, see table, page 236. Granger observes in the Lower Eocene that the Lost Cabin, Lysite, and Knight formations are very similar lithologically, although widely distributed geographically.

Substantial success has attended this effort of the American Museum parties to work downward from the typical Wind River into the Wasatch, so that we have now a complete faunal nexus from the top of the

[12] A. C. Veatch: Geography and Geology of a Portion of Southwestern Wyoming, with Special Reference to Coal and Oil. U. S. Geological Survey, Professional Paper No. 56, 1907.

Wind River to a point below the base of the Wasatch (Granger, 1910,[14] Sinclair and Granger, 1911, 1912); in other words, a sub-Wasatch fauna, a nexus which may be diagrammatically expressed as on page 243.

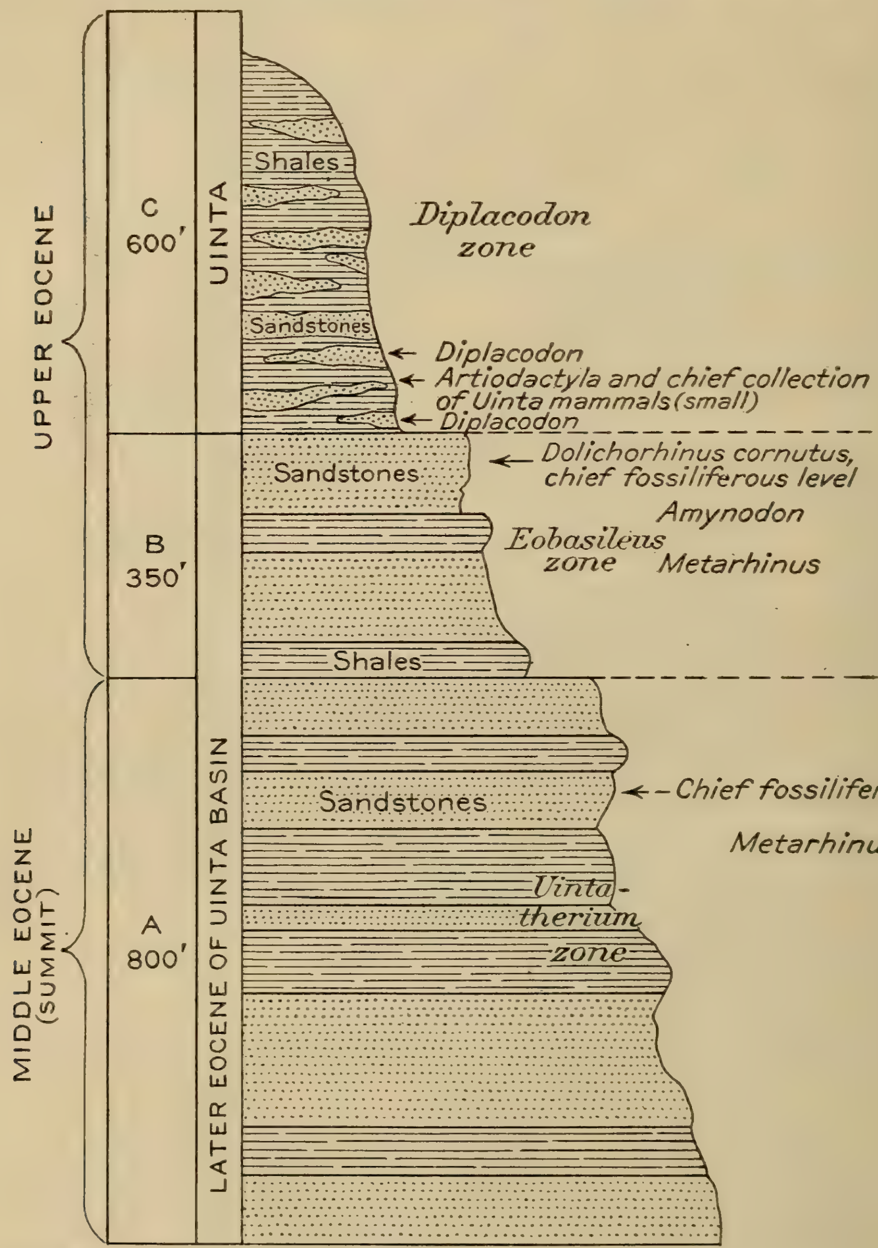

FIGURE 7.—*Middle and Upper Eocene of Uinta Basin, Utah.* (Modified after Peterson)

Upper: *Diplacodon* Zone
Middle: *Eobasileus* Zone
Lower: *Uintatherium* Zone

[14] Walter Granger: Tertiary Faunal Horizons of the Wind River Basin, Wyoming, with Descriptions of New Eocene Mammals. Bulletin of the American Museum of Natural History, July 16, 1910, pp. 235-251.

Sinclair, W. J., and Granger, Walter: "Eocene and Oligocene of the Wind River and Bighorn Basins." Bull. Amer. Mus. Nat. Hist., vol. xxx, art. vii, 1911.

Sinclair, W. J., and Granger, Walter: "Notes on the Tertiary Deposits of the Bighorn Basin." Bull. Amer. Mus. Nat. Hist., vol. xxxi, art. v, 1912.

Formations.	
	Lower Bridger fauna.
LOST CABIN	True Wind River fauna.
LYSITE	Fauna of genera common to Wind River and Wasatch.
"WASATCH"	True "Wasatch" fauna.
RALSTON	Sub-Wasatch fauna. Undiscovered life zones. "Fort Union."
	"Puerco" fauna.

The manner in which this result has been attained by the overlapping of mammalian life zones in four different sections is shown in more detail in the accompanying all-Eocene table.

The true Wind River fauna contains *Eotitanops* (early true titanothere) as well as *Lambdotherium.* The Lysite fauna and the true Wasatch fauna lack *Lambdotherium* and *Eotitanops.* *Systemodon* is limited to the true Wasatch (Knight) fauna. The sub-Wasatch fauna of

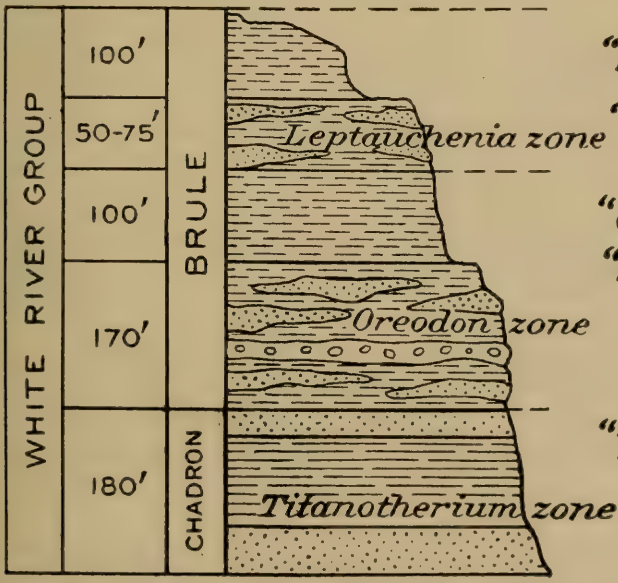

FIGURE 8.—*Oligocene of South Dakota. Section of Titanotherium Beds*
(After Wortman)
Upper: *Leptauchenia* Zone
Middle: *Oreodon* Zone
Lower: *Titanotherium* Zone

Synthesis of Eocene Correlations to the Year 1911

Life Zones	White River	Typical Uinta Formation	Typical Washakie Formation	Typical Bridger Formation	"Wind River" Beaver Divide	Typical "Wind River" Series	Big Horn Series, "Wasatch"	Typical Wasatch-Evanston
Titanotherium	C Oreodon B Titanotherium A				"White River" Titanotherium Cylindrodon Titanotheriomys Oreodon			
Protitanotherium and Diplacodon		Diplacodon Protitanotherium C			"Uinta" Diplacodon Amynodon Protoreodon Camelodon			
Eobasileus and Dolichorhinus		Eobasileus Dolichorhinus Metarhinus B	Eobasileus Dolichorhinus Metarhinus	? E				
Uintatherium and Manteoceras		Relatively barren A	Uintatherium Manteoceras	Uintatherium Manteoceras Mesatirhinus C D E	"Washakie" and "Bridger" (Barren)			
Palæosyops and Orohippus				Orohippus Palæosyops B				"Bridger"
Bathyopsis Eotitanops Lambdotherium				A	? "Wind River"	Lost Cabin Heptodon Eohippus Lambdotherium Eotitanops Bathyopsis Coryphodon Phenacodus	"Lost Cabin" Lambdotherium Eotitanops Heptodon Coryphodon Eohippus	"Green River"
Hyopsodus					Coryphodon Phenacodus Eohippus	Lysite Coryphodon Eohippus Hyopsodus (large) etc.	"Lysite" Coryphodon Eohippus Hyopsodus (large) etc.	Knight
Coryphodon and Systemodon							"Knight" Coryphodon Systemodon Eohippus Phenacodus	Coryphodon Phenacodus Eohippus etc.
Phenacodus ?							Ralston Phenacodus Limnocyon Esthonyx Coryphodon Bathyopsis	? "Fowkes"
								? "Almy"

the new Ralston formation contains a mammal resembling *Bathyopsis* of the typical Wind River; also a number of more primitive species of Wasatch type.

The annectant life zones between this sub-Wasatch and the well known Torrejon, Fort Union (see Knowlton,[15] 1909), and Puerco faunæ all remain to be discovered. When these are discovered, as they surely will be, we may claim for the American Eocene the unique distinction of presenting a perfectly continuous life chain of mammals from the base to the summit.

Oligocene

No less important is the remarkable sequence from Lower Eocene to Lower Oligocene discovered by Granger on Beaver Divide, Fremont County, Wyoming. Here, overlying unmistakable "Wind River beds," are brown depositions probably of "Bridger" age, so identified because above them lie true depositions of "Uinta" age containing the highly characteristic forms *Diplacodon, Amynodon, Protoreodon, Camelodon.* These were identified through the presence of the rhinoceros *Amynodon intermedius.* Still higher are true depositions of the basal Oligocene epoch identified by the equally characteristic species *Titanotherium heloceras.*

In the true Oligocene of the Western plains little progress has been made beyond the classic subdivisions established many years ago by Leidy (1869), Hatcher (1893), and Wortman (1893), into Lower, or *Titanotherium* zone, Middle, or *Oreodon* zone, and Upper, *Protoceras* and *Leptauchenia* zones.

The faunistic succession of the Oligocene has, however, been continued with great geologic precision in the John Day of Oregon, by Merriam (1091, 1906) and Sinclair.[16] Here, again, we meet the *Leptauchenia* zone, uppermost member of the White River series, continued above into the *Diceratherium* zone, which in turn is capped by the *Promerycochœrus* zone.

Here quite arbitrarily we mark the transition from the Oligocene to the Lower Miocene. *Promerycochœrus* happens to be an abundant and highly characteristic oreodont. It is associated with many other characteristic species, so that when *Promerycochœrus* is again found along the

[15] F. H. Knowlton: The Stratigraphic Relations and Paleontology of the "Hell Creek Beds," "Ceratops Beds" and Equivalents, and their Reference to the Fort Union Formation. Proceedings of the Washington Academy of Science, vol. xi, no. 3, 1909, pp.179-238.

[16] W. J. Sinclair and J. C. Merriam: Tertiary Faunas of the John Day Region. Publications of the University of California, Department of Geology, vol. 5, no. 11, 1907, pp. 171-205.

Upper Niobrara River of the great plains of western Nebraska (see figure 10), with a substantially similar group of mammals, containing no new migrants, but all slightly more advanced specific or mutative stages, we feel assured that we are again in the same pure endemic or American faunal period.

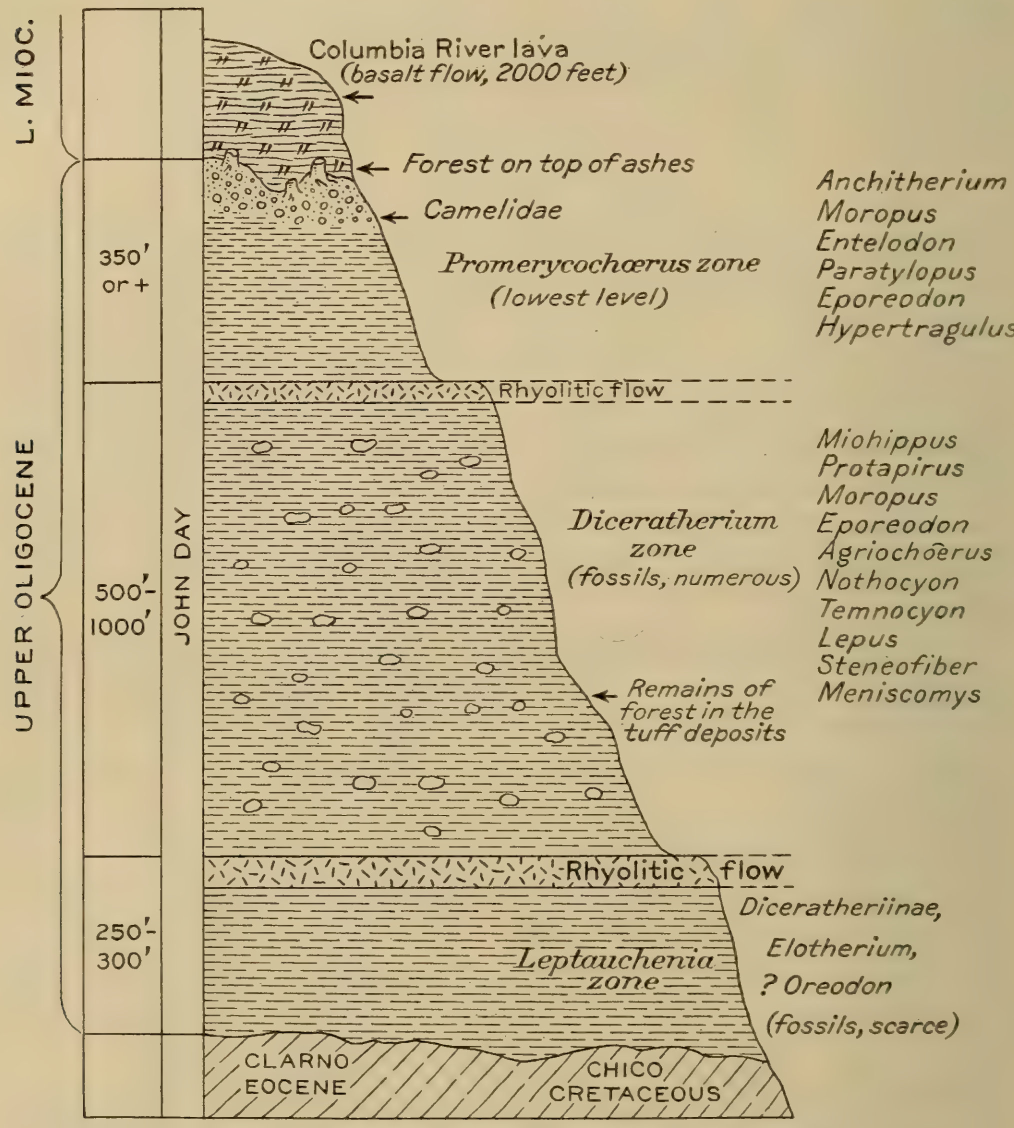

FIGURE 9.—*Oligocene and Lower Miocene of John Day Basin, Oregon*

(Modified after Merriam)

Upper : *Promerycochœrus* Zone
Middle : *Diceratherium* Zone
Lower : *Leptauchenia* Zone

Quite arbitrarily, because we have no exact means of close comparison with the Lower Miocene of France, which must be taken as our standard, this *Promerycochœrus* fauna, together with the giant *Dinohyus* and

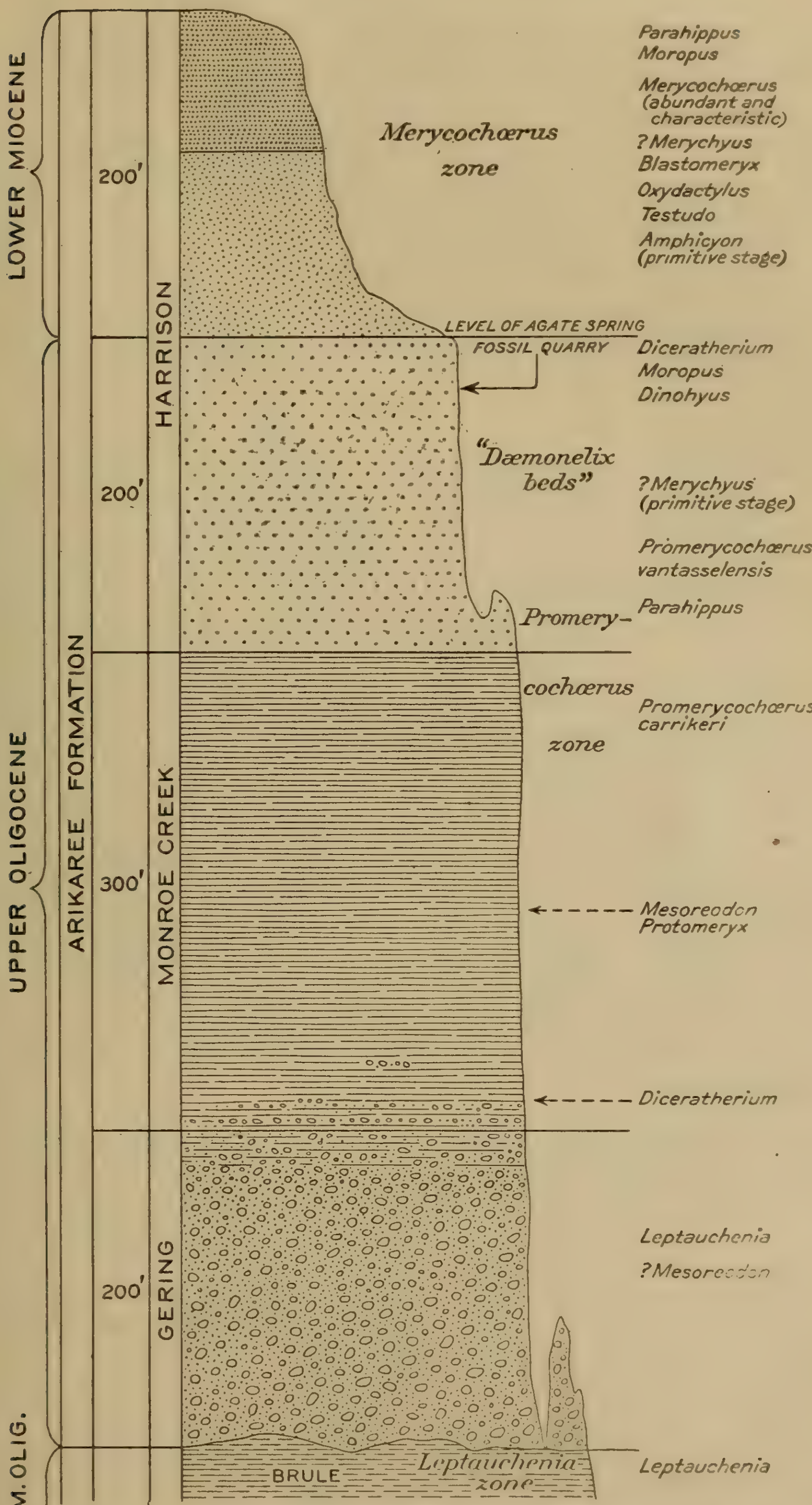

FIGURE 10.—*Section of the Oligocene-Miocene Transition on the Niobrara River, western Nebraska.* (Modified after Peterson)

Upper : *Merycochœrus* Zone
Middle : *Promerycochœrus* Zone
Lower : ? *Diceratherium* Zone
Basal : *Leptauchenia* Zone

Moropus, is regarded as representing the close of Oligocene life, and the succeeding oreodont, *Merycochœrus*, is regarded as marking the opening phase of the Miocene. Our knowledge of the life of these two very rich zones is due to the discoveries of the Messrs. Cook, of Agate, Nebraska, and the energetic work of parties from the Nebraska, Carnegie, and American Museums. This annectant Oligocene-Miocene fauna represents, in fact, the greatest faunistic advance of the decade. A practically unknown life period has become one of the most fully known, with an abundance of complete skeletons and an overwhelming wealth of material.

Miocene

Ranking as next in importance to the wonderful progress in the Eocene is the Miocene history of the past decade, which we owe to Hatcher (1902-1904),[17] Peterson (1907), Matthew (1907), and Cook. The Lower Miocene has been spoken of above as distinguished by the presence of *Merycochœrus* and absence of *Promerycochœrus* and *Dinohyus*. This fauna otherwise closely articulates with the subjacent fauna.

The *Middle* Miocene is a clearly circumscribed fauna without known transitions either above or below. Its correlation is chiefly the work of Matthew (faunal character, 1901), of Merriam (Mascal, 1907), of Douglass (Madison Valley, 1903), based on original field work and a synthesis of the earlier work of Cope (1873, 1897-1898) and of Scott (Deep River, 1895), together with a freshening discovery of new and more complete forms, and many direct additions to our knowledge. The latest formation to be added to this correlation is the Virgin Valley of Nevada, which Merriam (1911) and Gidley regard as contemporaneous or a little earlier in deposition than the Mascal of Oregon, which is in the typical *Merychippus* zone.

The zonal type of this Middle Miocene stage is *Ticholeptus*, a short-faced oreodont which, with *Merychippus* and the first Proboscideans of North America, ties together formations widely scattered in Oregon, Montana, and Colorado. We greatly need more accurate geologic sections and more concise data regarding this Middle Miocene stage.

A sharply defined as well as very long time interval separates the Lower Miocene fauna from this Middle Miocene fauna.

The *Upper* Miocene is another clearly defined faunal period, the zone of *Procamelus*, *Hipparion*, and *Protohippus*, mammals which tie together scattered river channel and flood plain deposits in Nebraska, South Da-

[17] J. B. Hatcher: An Attempt to Correlate the Marine with the Non-Marine Formations of the Middle West. Proceedings of the American Philosophical Society, vol. xliii, no. 178, October-December, 1904, pp. 341-364.

kota, Colorado, Montana, New Mexico, and Texas (Gidley, 1903).[18] Geologic studies and sections are also greatly needed in this period.

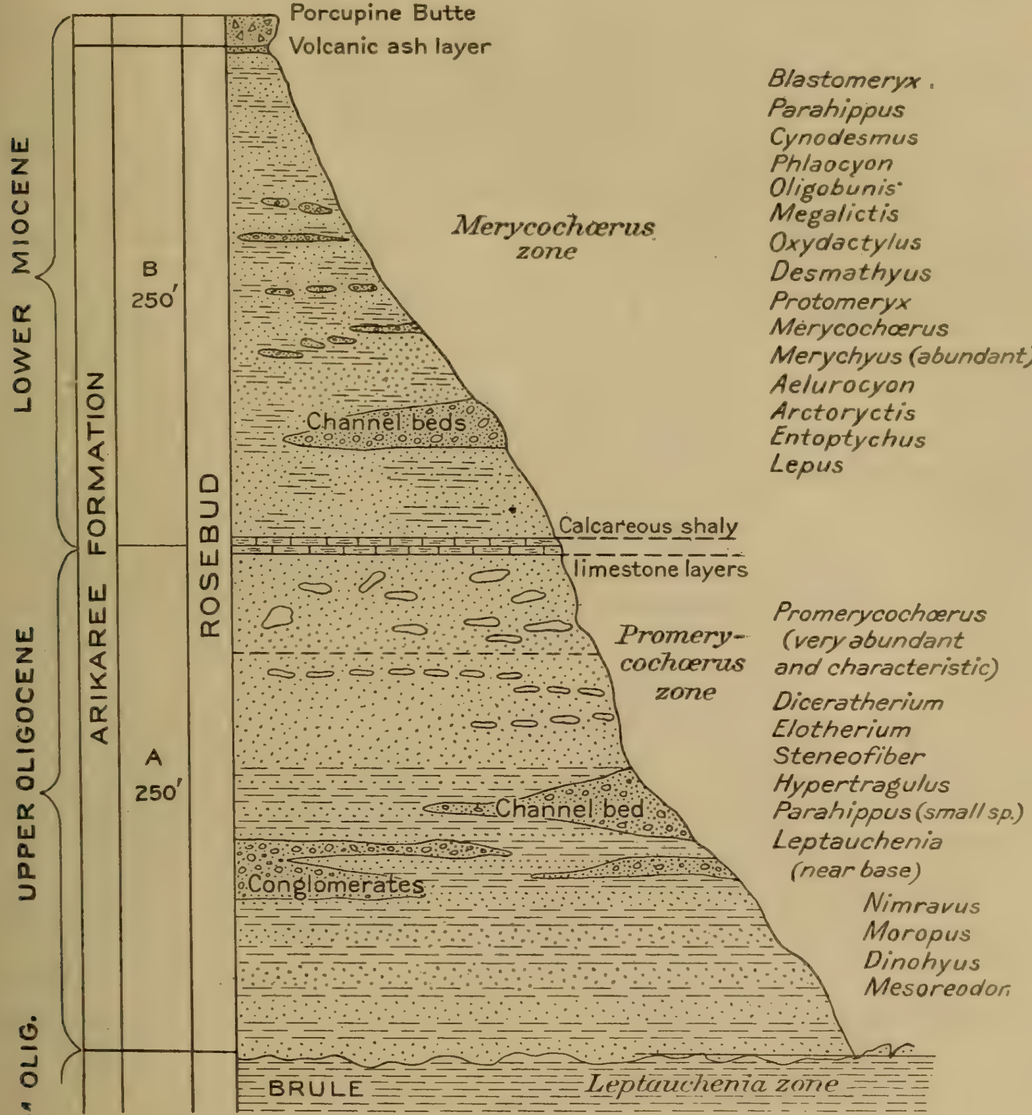

FIGURE 11.—*Oligocene and Lower Miocene of South Dakota*
(After Matthew and Thompson)
Upper: *Merycochœrus* Zone
Middle: *Promerycochœrus* Zone
Lower: *Leptauchenia* Zone

PLIOCENE

The beginning, the succession, and the close of the Pliocene still await correlation and definition. It will be observed that as we progress from

[18] J. W. Gidley: The Fresh-water Tertiary of Northwestern Texas. Bulletin of the American Museum of Natural History, vol. xix, art. xxvi, November 21, 1903, pp. 617-635.

the Eocene upward in the history of American formations they become more and more scattered, with an ever increasing number of intervals and breaks, thus:

EOCENE	Continuous
OLIGOCENE	Nearly continuous.
MIOCENE...............	Breaks between Lower, Middle, and Upper.
PLIOCENE....	Wide and unfilled intervals.

That all these intervals will be filled in time there can be little question. Rich faunistic additions during the past decade are those indicated in the column below in large capital letters.

Life Zones:	*Formations and States.*	*Date of Discovery.*	
Elephas, Equus............	Peace Creek of Florida	Dall,	1891.
" "	Loup River of Nebraska...	Meek, Hayden,	1861–2.
Glyptotherium	Blanco of Texas.		
Ilingoceras, Sphenophalus...	Thousand Creek of Nevada.	Merriam,	1909–11.
Neotragoceras	SNAKE CREEK (Ogallala) of Nebraska.	Matthew,	1909.
Pliohippus, Alticamelus.....	RATTLESNAKE of Oregon ...	Merriam, Sinclair,	1907.
Peraceras	Alachua Clays of Florida...	Leidy,	1896.
Peraceras	Republican River of Kansas.	Cope, Sternberg,	1882.

The base as well as the summit of our Pliocene still lacks definition in comparison with that of Europe. The Snake Creek (Matthew, Cook, 1909)[19] and Thousand Creek faunæ have been compared by Matthew and Merriam with that of the Pikermi, or Upper Miocene, of Greece. The occurrence of *Neotragoceras,* the earliest bovine recorded in America in the Snake Creek, and of several antelopine forms in the Thousand Creek, are facts of prime importance in paleogeographic science; they indicate an outlying connection with the great bovine and antelopine fauna of southern Asia.

PLEISTOCENE

The first physiographic or forest and plains subdivision of the Lower Pleistocene fauna is that of Matthew (1902).[20] The first attempt to subdivide the entire American Pleistocene faunistically is that of Osborn[21] (1910) and is essentially a forecast, because Pleistocene divisions

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[19] W. D. Matthew and Harold J. Cook: A Pliocene Fauna from Western Nebraska. Bulletin of the American Museum of Natural History, vol. xxvi, art. xxvii, September 3, 1909, pp. 361-414.

[20] W. D. Matthew: List of the Pleistocene Fauna from Hay Springs, Nebraska. Bulletin of the American Museum of Natural History, vol. xvi, art. xxiv, September 25, 1902, pp. 317-422.

[21] H. F. Osborn: The Age of Mammals in Europe, Asia, and North America. 8vo. The Macmillan Company, New York, October 25, 1910, 635 pages.

depend in part zoologically on a far more precise distinction and comparison of species than has yet been made; an important piece of research which is now in the hands of Dr. O. P. Hay. Pleistocene life in Alaska has been reviewed by Quackenbush[22] (1909).

Pleistocene correlation depends geologically on the relation of the fauna to the six glacial and five interglacial stages which Chamberlin, Salisbury, Calvin, and other authorities on Quaternary geology adopt. It is obvious that if geologists succeed in correlating the American glacial advances with those in Europe our paleontologists will secure the means of correlating such interglacial faunæ as are discovered with the great pre-, inter-, and post-Glacial faunæ of Europe. Such discoveries in America now include only the first interglacial, or Aftonian fauna (Calvin, 1909), and a sparse fauna of the second interglacial, or Yarmouth. Very precise determination of the species and mutations in these and in other still to be discovered interglacial fauna will gradually clear up these highly important problems. A virgin field of research awaits the Pleistocene investigator.

The zonal division into four stages suggested by Osborn is as follows:

I.	II.	III.	IV.
PLAINS FAUNA.	FOREST FAUNA.	WOODLANDS AND BARREN GROUND.	WOODLAND AND PLAINS.
Equus, *Camelus*. *Paramylodon*, *Platygonus*, *Machærodus*.	*Equus*, *Bison*. *Megalonyx*. *Cervus*, *Alces*. *Euceratherium*.	*Ovibos*. *Rangifer*. *Mastodon*. *Elephas primigenius*.	*Cervus* and many modern species of mammals.
Non-arrivals: Deer (*Cervus*). Bear (*Ursus*). Goats (*Oreamnus*). Sheep (*Ovis*).	Non-arrivals: Caribou (*Rangifer*). Musk ox (*Ovibos*).	Non-arrivals: Few modern species of mammals.	Disappearance of horses, tapirs, mastodons, and mammoth.
Pre-Glacial and Early Interglacial.	Interglacial.	Late Interglacial.	Post-Glacial.

SOUTH AMERICA[23]

The correlation of the mammal faunæ of the northern continents is long since settled in its fundamentals. Progress in the last decade has been in the precision of detail, local and intercontinental. No one now questions the broader equivalence of epochs, the approximate position of the greater formations in the time scale.

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[22] L. S. Quackenbush: Notes on Alaskan Mammoth Expeditions of 1907 and 1908. Bulletin of the American Museum of Natural History, vol. xxvi, art. ix, March 24, 1909, pp. 87-130.

[23] Notes prepared by Dr. W. D. Matthew.

But with South America a wide divergence of opinion exists as to the time equivalence of its mammal faunæ with those of the northern world. This is not because of lack of evidence. Few faunæ compare with those of the Argentine Republic in numbers, variety, and perfection of material. It is not because of lack of interdigitated marine formations; hardly even in Europe are the relations of the marine and continental succession so clearly displayed. It is rather because the faunæ are so remote geographically and zoologically from those of the northern world that their real time equivalence becomes a matter rather of interpretation and inference than of direct evidence. The northern faunæ, derived from a common northern center, are represented on each side of it by equivalent and closely related types. The southern faunæ, if derived from the north, are survivals lagging behind those of the northern world; if derived from the south they will be more progressive than in the northern world. Hence a southern fauna will be regarded as either older or younger than its evolutionary equivalent in the north, according to the theories held as to the source of the fauna. Herein apparently lies the basis of the wide divergence of opinion that still exists regarding the true age of the Argentine faunæ. While this is most marked in the continental faunæ it should be remembered that it is also true of the marine faunæ.

Great progress has been made in the last decade toward accumulating adequate data to solve this problem. Especially important are the collections secured by the Princeton and American Museum expeditions to Patagonia, chiefly in the Santa Cruz formation, and studied and described by Scott, Ortmann, Stanton, and Sinclair; the collections obtained by the Paris Museum from the underlying formations, and described by Gaudry, and the explorations of Santiago Roth[24] (1908) for the La Plata Museum. The recent work of Dr. F. B. Loomis for Amherst Museum and of Bailey Willis for the Argentine government will also add largely to the available data. The geological observations of Steinmann, Nordenskjold, and other geologists, and the paleontological studies of Cossmann, Canu, Wilckens, Ameghino, Roth, von Ihering, and others likewise afford information of the highest importance.

These studies have served to fix authoritatively many of the data, stratigraphic and morphologic, from which the problem must be solved. The problem itself must still be regarded as an open one.[25] None of the

[24] Santiago Roth: Beitrag zur Gliederung der Sedimentablagerungen in Patagonien und der Pampasregion. Neuen Jahrb. f. Mineral. Geol. u. Pal., Band xxvi, 1908, pp. 92-105.

[25] Le classement des couches patagoniennes a fait et fera encore, couler des flots d'encre. Cossmann in Revue Critique de Paleozoologie, 1907, p. 181.

attempted solutions have taken into account all of its elements or brought into accord all the evidence.

The foundations of North American paleogeography, or of the more precise determinations of the land connections with South America, the Antillean archipelago, and with Asia obviously rest largely on the filling in of the successive faunistic and geologic stages in the American column.

Europe

In Europe, Dollo[26] (1909) in Belgium, Stehlin[27] in Switzerland (1903-1910), Depéret[28] (1905)[30] and his colleagues and students in France have made great advances in the Eocene to Miocene correlation, and we await the Pliocene section with impatience. Stehlin has been another able contributor (1904)[29] to correlation in France and Switzerland. Both these authors have discussed American faunistic connections and migrations, but neither has furnished us as yet with the highly desirable stratigraphic sections. Osborn (1910) has plotted the Eocene to Pliocene localities on the map of Europe chiefly according to the correlations of Depéret.

The mammal life of Europe, in which the vertebrate paleontologist is constantly aided by the interstratification of marine shell-bearing deposits with continental or fluvio-marine mammal-bearing deposits, is obviously the standard or criterion for the exact subdivision of the American Tertiaries in the future. Only in the Tertiaries of the coast of Florida and to a limited degree of the California coast does the American paleontologist enjoy this advantage. As aforesaid by the present writer, it may be stated that Europe will surely set the time scale of the epochs and stages and America must follow.

Asia

Quite recently exact exploration has been revived in Asia, and the

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[26] L. Dollo: The Fossil Vertebrates of Belgium, Correlation Bulletin no. 2. Annals of the New York Academy of Science, vol. xix, no. 4, pt. i, 1909, pp. 99-119.

[27] H. G. Stehlin: Saugetheire des Schweizerischen Eocæns. Abh. Schw. Pal. Gesell., vols. xxx-xxxvi, 1903-1910.

[28] Charles Depéret: Note sur la Succession Stratigraphique des Faunes de Mammifères Pliocenes d'Europe et du Plateau Central en Particulier. Bull. Soc. Géol. de France, 3e Ser., tome xxi, 1893, p. 524.

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[29] H. G. Stehlin: Sur les Mammiferes des Sables Bartoniens du Castrais. Bull. d. l. Soc. Géol. de France, 1904, 4°, ser. t. iv, 1904, pp. 445-475.

[30] F. Roman, M. Flyche, and A. Torres: Le Neogene Continental dans la Basse Vallee du Tage (Rive Droite). Ire Partie. Paleontologie, Avec une Note sur les Empreintes Vegetales de Pernes (par M. Fliche). 2 Partie. Stratigraphie (par Antonio Torres). Comm. du Service Géol. du Portugal, Lisbon, 1907, 4to.

enormously important and interesting deposits on the great ancient flood plains south of the Himalayas are being investigated by Pilgrim[31] (1907) and Couper. Schlosser (1902)[32] has also analyzed and faunistically examined the sparsely known fauna of China. Osborn (1910, pages 323-335) has put together these results (page 324) in a preliminary correlation which awaits critical revision by Pilgrim and Couper from their direct observations in the field. It is eminently desirable, in fact it is one of the prime *desiderata* of modern paleontology, that stratigraphic and faunistic sections of the rich formations of Baluchistan, of Sind, of the Punjab, and of the Himalayan Siwaliks, as well as of Burmah be assembled and published. The most epoch-making discoveries in the next decade in mammalian paleontology may be made in Asia.

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[31] Guy E. Pilgrim: The Tertiary and post-Tertiary Fresh-water Deposits of Baluchistan and Sind, with Notices of New Vertebrates. Records of the Geological Survey of India, vol. xxxvii, pt. 2, 1908, pp. 139-166.

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[32] Max Schlosser: Die fossilem Säugethiere China's. Centralblatt f. Mineraligie. Geologie u. Palæontologie Jahrg., 1902, pp. 529-535.

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EVOLUTIONARY EVIDENCES

BY S. W. WILLISTON

In the time allotted me I can hope to give little more than a very brief summary of the more important evidences of evolution furnished by vertebrate paleontology during the past ten years; nor could I speak even briefly of much of my subject had not kind friends, especially Doctors Gregory and Eastman, come to my aid. The field of vertebrate paleontology has grown so wide that no longer can any one person make a pretense even to that universal knowledge rightly claimed by our predecessors a score of years ago.

Perhaps the most encouraging sign of advancement in our science during the past ten years has been the recognition of certain methods or factors of evolution that permit us to orient ourselves better, to discern more clearly the true lines of evolution, and of these I refer more especially to parallel evolution. We have been deceived in the past, time without end, in almost every branch of animal and vegetable life, by adaptive characters, characters evolved in response to like environmental conditions, so often imputed to real heredity. From the time of Peter Camper, when whales were breathing fishes, to the present, some of the most difficult problems in the determination of real phylogenies have been due in large part to the confusion between adaptive and genetic characters. Such problems will always remain with us, but we are now on guard against their ofttimes insidious deceptions.

The progress of the past ten years in most branches of vertebrate paleontology has been very encouraging, in the more careful study of faunas, their relationships and sequences—a progress which has opened up a new science, that of paleogeography, a science yet in its infancy and full of snares and pitfalls for the unwary. The pioneers in vertebrate paleontology left us many things imperfectly or erroneously known. We are no longer dependent to the extent that we were a score of years ago upon a tooth or a vertebra or a limb bone as foundations for speculations, no longer tempted as we were to use them as mere springboards for flights of imagination, which too often, alas, reached terra firma again with disastrous results. The impelling spirit of genus and species making has given place to other ideals more in accord with modern science, and the acquisition of facts has largely taken the place of the formulation of vague theories. This, it seems to me, is the province of our science in the immediate future, as our President truly said a year

ago. Very much yet remains in the completion of our knowledge of old things, and when things are well known, he who runs may read.

Among fishes, of which I can speak but briefly, perhaps the most far-reaching, if not important, result of the past ten years has been the practical demonstration of the Thacher-Mivart-Balfour theory of the origin of limbs from lateral dermal folds; and this is especially pleasing to me, since it is to a dear friend and colleague, the late Professor Thatcher, that the credit for the conception of this theory is chiefly due.

The recapitulation theory, to which the paleontologist yet gives full faith, has been strengthened by the discoveries among elasmobranchs and ganoids; and, to use the words of Eastman, "extensive series of progressive modifications have been traced among the cochliodonts, and others, still more remarkable, among the so-called Edestidæ." While the affinities of the Arthrodira are still the subject of an animated discussion, we may rest confident that their final disposition is almost in sight. That they are no longer united with the Dipnoi is at least one important step.

To the bystander there are few things in vertebrate paleontology of more profound interest in the evolution of the vertebrates at the present time than the relations of these forms which stand along the border lines of the higher types. The affinities of the dipnoans and crossopterygians to the higher air-breathers, the rôle in general that the ganoids have played, the many problems yet awaiting solution among the elasmobranchs, all have an importance second to none others in the evolution of the vertebrates.

Among the Amphibia the discoveries of the past few years have been none the less important and far reaching. While, unfortunately, the immediate relations of this class to the lower Anamnia are still involved in great obscurity, we have a more confident expectation than ever before of the early solution of their chief problems. The field is still one of speculation, sometimes crude; but speculations are at least useful in their demolition. The phylogenetic relations of the modern amphibians with the early stegocephs have become more intimate by the recognition of a Urodele in the early Permian and an Anuran in the Jurassic; their direct ancestry from the Branchiosaurs has been placed on firmer grounds, if not established. The Microsauria have lost much of their former coherency, their relationships on the one hand with the true reptiles, on the other with the true amphibia, more demonstrable. The temnospondyls have established their genetic relationships beyond a doubt with the reptiles, and for the first time the practically complete structure of any member of the order has been made out; the structure of their carpus

and tarsus, if not feet, has been eventually determined. More important than all these, perhaps, is the nearly complete demonstration of the Cope theory of the origin of holospondylous vertebræ from the temnospondylous, by the discovery of forms that are almost the missing links, forms that seem to demonstrate the absolute morphological identity between the intercentra of the modern reptiles and the hypocentra of the ancient amphibia.

The progress in our knowledge of the Reptilia, at least so far as the broader problems of phylogeny (and by phylogeny I mean evolution) are concerned, has been perhaps greater than in any other class of vertebrates during the past ten years—a progress which while it has cleared up many things has involved others in great obscurity. One by one the characters distinguishing this class from the Amphibia have been broken down, till but few remain. The greater size of the pterygoidal vacuities of the palate and perhaps the presence of a distinct intermedium pedis are the last and only characters peculiar to the Amphibia now remaining. Indeed, so closely allied are the forms already known that it is possible to distinguish finally the skeleton of a cotylosaur from one of a temnospondyl, only by the structure of the palate, the reduced size of the intercentra, and the fused intermedium of the tarsus. But an actual connecting link has not yet been discovered; the true microsaurs have complicated the problem and thrown back the actual divergence of the classes at least as far as the early Pennsylvanian.

On the other side, perhaps the most interesting of all the evolutional advances in paleontology that have been made during the past ten years is the practical demonstration by Broom of the origin of the mammalia from the theriodont reptiles. Nearly every distinguishing character between these two classes has now been bridged over—the double occipital condyle, the false palate, heterodont teeth, reduced and almost vestigial quadrate and mandibular bones, the pectoral and pelvic girdles and the feet.

The primitive reptilian foot, dating from the middle Pennsylvanian, first made known by Cope, has been established, a foot differing but little from that of the modern Sphenodon.

Within the reptile class itself, among the most striking evidences of evolution that have been presented in late years are those of the ichthyosaurs by Merriam. While unfortunately they throw no new light on the ultimate origin of the order, his observations have shown clearly some of their chief lines of evolution; and of nearly equal importance are the evidences produced in recent years of the derivation of the mosasaurs from the terrestrial forebears of the modern monitors. I know of no

forms answering better as actual connecting links anywhere in vertebrate paleontology than do the subaquatic Aigialosaurs of the Dalmatian region, connecting the mosasaurs with terrestrial lizards.

Among nearly every other order of the reptiles have new discoveries and new interpretations thrown light on their evolution; the shortening of the limb bones and peculiar modifications of the skull among plesiosaurs, the extreme specializations of the later pterodactyls, the progressive modifications, not numerous it is true, of the Chelonia, are too numerous to describe in detail. The Parasuchia, by unanimous consent, have been divorced from the Crocodilia, and much new light has been thrown upon their relationships. The phylogeny of the Crocodilia has been placed on a better foundation, and a remarkable new divergent phylum, the Thalattosuchia, has thrown a flood of light on the evolution of aquatic Amniota, helping to explain those resemblances that so long seemed mysterious between the ichthyosaurs, plesiosaurs, mosasaurs, crocodiles, thalattosaurs, champsosaurs, mesosaurs, etcetera. Those adaptive resemblances of the aquatic air-breathers, that made the whale a breathing fish till the beginning of the last century and the ichthyosaurs real fish reptiles till twenty years ago, are no longer seductive; we have now a clearer viewpoint here as in so many other places. Perhaps in no other order has there been a wider and fuller accumulation of knowledge, accurate knowledge, than among the dinosaurs. While in the end I do not think that this knowledge has greatly modified the phylogenetic conceptions of Marsh and Cope, it has at least excluded much of error.

Especially has our knowledge of the early reptiles acquired in the past few years thrown a flood of light on the evolution of the class, at least in the revelation of earlier errors. The cotylosaurs and theromorph reptiles have been brought into the most intimate relations, till their separation has become a matter of the most trivial structural characters. The connecting chain between the most generalized of reptiles, as represented by *Seymouria*, to the most generalized of mammals is now almost complete: nowhere are there differences that in themselves are of more than family value, perhaps not even that. That we attribute to rudimentary temporal vacuities of *Ophiacodon*, or the vestigial quadrate of the theriodonts ordinal or class values, is merely a matter of taxonomic convenience. Classification will have attained its highest perfection when nothing more than specific differences are the final distinction between families, orders, and classes.

Among the birds not so much has been done perhaps in paleontological discovery as in the reinterpretation of the many accrued facts. Perhaps no positive addition has been made to our knowledge of their

derivation; the gap between the archosaurian phylum and Archæopteryx is as wide as ever. But in the new classifications that have taken the place of the older Ratitæ and Carinatæ we have, I am sure, approached more nearly the real evolution of the birds than ever before.

In the field of the mammals the investigators have been so many and so able, the collections that have been made so enormous in amount, that the subject were well worthy a separate place on this program. Indeed I should feel lost in its discussion had not Doctor Gregory kindly come to my aid; and perhaps the first comment that I can make is in his own words, with which, so far as my knowledge goes, I quite agree: "The chief advance made in mammalian paleontology during the past decade lies not so much in the discovery of new and strange faunæ, or of long-sought 'missing links,' as in the steady development along familiar lines, especially in thorough morphological and systematic revision and in faunal revision. Perhaps the greatest progress has been in faunal correlation, due to systematic exploration by various museums, and to systematic revision of the faunæ. Along with this has progressed a reinterpretation of familiar data, a wider understanding of the comparative anatomy of recent mammals, and attempts to synthesize and summarize existing knowledge of recent and fossil mammals." The names of all those to whom this advancement is due are too numerous to mention here; some of the investigators, at least, are known to my hearers by their participation in the present symposium.

First of all perhaps are the evolutionary evidences, ones that have rightly claimed more attention from the scientific world than any others in vertebrate paleontology during the last decade, furnished by the discoveries of the Fayûm of Africa—discoveries that have carried back the history of the Proboscidea in that continent to the Oligocene, if not the Eocene, paralleled only by those classic ones by Marsh in the history of the horse. None the less interesting are the indissoluble bonds they have disclosed between the Proboscidea and the Sirenia. These discoveries also have thrown a bright light over both the Hyracoidea and the Cetacea. Whether the Archæoceti have been derived from the Creodonta, as Fraas believes, or from the Insectivora, as Matthew insists, is a minor problem to that of the terrestrial ancestry of the Cetacea. The discovery of true anthropoid apes in the Oligocene of Africa by Schlosser is another important bit of evidence in man's ancestry. The recognition of the phylogenetic coherency of the Subungulata and of the Notungulata has been an important advance in the taxonomy of the Mammalia.

Much has been added to our knowledge of the ancestry of the horse by Gidley, of the phylogeny of the Cervidæ and Carnivora by Matthew, of

the Antilocapridæ and Antilopidæ by Merriam, of the rodents by Scott and Matthew, the Titanotheres and Rhinoceroses by Osborn, the Carnivora by Wortman, the Litopterna and Edentata by Scott, the Multituberculata by Gidley, the Marsupialia by Bensley and Sinclair, the Insectivora by Wortman, Scott, and Matthew, and various artiodactyls by Peterson, Loomis, Matthew, and Douglass; and this list includes only the names of our own immediate colleagues. To all these must be added the masterly summarization of our existing knowledge and its coordination and correlation by Osborn and Gregory.

In no other class of animal or vegetable life has classification—that is, real phylogeny—reached the high plane that it has in the Mammalia; nowhere does taxonomy, that bugbear of the microscopist, approximate so near the final truth, and this happy result has been due chiefly to the paleontologist. To him has been and always will be the last word in taxonomy—that is, evolution.

CONTRIBUTIONS TO GEOLOGIC THEORY AND METHOD BY AMERICAN WORKERS IN VERTEBRATE PALEONTOLOGY

BY WILLIAM J. SINCLAIR

Since 1901 vertebrate paleontologists have named and described sixteen formations on the basis of fossils contained therein as follows:

CRETACEOUS

Hell Creek (Upper Cretaceous), Montana. Brown, 1907.

EOCENE

Lost Cabin (Lower Eocene), northwestern Wyoming. Sinclair and Granger, 1911.

Lysite (Lower Eocene), northwestern Wyoming. Sinclair and Granger, 1911.

MIOCENE

Mascall (Middle Miocene), Oregon. Merriam, 1901.
Pawnee Creek (Middle Miocene), Colorado. Matthew, 1901.
Gering (Lower Miocene), Wyoming-Nebraska. Hatcher, 1902.
Monroe Creek (Lower Miocene), Wyoming-Nebraska. Hatcher, 1902.
Harrison (Lower Miocene), Wyoming-Nebraska. Hatcher, 1902.
Clarendon (Upper Miocene), Texas. Gidley, 1903.
Panhandle (Middle or Lower Miocene), Texas. Gidley, 1903.

Rosebud (Lower Miocene), South Dakota. Matthew and Gidley, 1904.
Virgin Valley (Middle Miocene), Nevada. Merriam, 1910.

PLIOCENE

Rattlesnake (early Pliocene), Oregon. Merriam, 1901.
Snake Creek (Lower Pliocene), Nebraska. Matthew and Cook, 1909.
Thousand Creek (Lower Pliocene), Nevada. Merriam, 1910.

PLEISTOCENE

Rock Creek = Sheridan (Pleistocene), Texas. Gidley, 1904.

Many of the names proposed either have been or will be retained as the designations of epochs in the standard time scale for the non-marine Tertiary. They represent both the discovery of entirely new fossiliferous horizons and the subdivision of previously known formations necessitated by a fuller knowledge of the faunas contained therein.

Correlation studies have kept pace with the naming and characterization of new horizons. In Osborn's "Age of Mammals" (1910) we have a remarkably complete and satisfactory summary of all that is known to date of the faunal and time relations of the mammal-bearing beds of Europe and North America. Less progress can be reported in the correlation of marine with non-marine Tertiary formations. In North America, the Atlantic border region holds out little promise for the future except, perhaps, in Florida, but on the Pacific side, even though the whole problem of the relation of the epicontinental formations east of the Sierra Nevada to the marine deposits of the coast region is far from a definite settlement, the discovery of fragmentary mammalian remains of late Miocene to Pliocene age in the largely marine Jacalitos and Etchegoin formations of the western San Joaquin Valley and of a mammal-bearing Upper Miocene horizon in the Mohave Desert suggest that, ultimately, correlations may be established. In South America, where marine beds are interstratified with non-marine formations affording vertebrates, much may be hoped for, but so far there has been fundamental difference of opinion between Argentinian geologists and paleontologists and the rest of the geological world, the former contending for a greater age for their fossiliferous formations than northern workers are disposed to admit. It seems to be positively established that dinosaurs and mammals occur in the Notostylops beds. The mammals are not like those known elsewhere from the Cretaceous, but are of highly advanced type, comparable to those of the Puerco Paleocene of North America. Either we must admit that dinosaurs existed during the Tertiary in South

America or change our ideas regarding Cretaceous mammalian types. The Santa Cruz formation has been referred to the Eocene, Oligocene, and Miocene, and the Patagonian, Pyrotherium, and other less well established intervening beds shifted about at will from Cretaceous to Tertiary. Fortunately, Dr. F. W. True has found a clew to the mystery in the identification of the same genera of whales in the Patagonian formation of Argentina as in the Chesapeake Miocene of our Atlantic coast. Omitting South American horizons, the chronologic and correlation standards of the "Age of Mammals" are now in use by all American and European workers in vertebrate paleontology.

The most important recent contribution to geologic theory which may be credited in part to vertebrate paleontology has been the substitution of æolian and fluviatile agents for lacustrine in explaining the origin of continental Tertiary formations. Matthew's paper, "Is the White River Tertiary an Æolian Formation?" (1899), was, in this respect, epoch-making. It was followed by contributions from other workers, both geologists and paleontologists, so that now, of the numerous fresh-water seas which used to spread so extensively over our geologic maps and through the pages of our text-books, only the Florissant and Green River lakes and the white layers in the Bridger remain. Evidence from many sources, dealing with the nature of the fossils and the conditions controlling their intombment and preservation, changes in faunal facies with changing lithology, the stratigraphic interrelations of different portions of the fossil-bearing sediment, the origin of the sedimentary material, etcetera, was presented, but it was not until the problem was attacked by the methods of microscopic petrography that the lacustrine theory was finally abandoned. Calkins's "Contributions to the Petrography of the John Day Basin," published in 1902, is the first paper dealing with the microscopic petrography of formations affording fossil vertebrates, and although a great field was thereby opened for the investigation of epicontinental sedimentation in its relation to diastrophism, structure, and life conditions, few have been sufficiently interested to continue these investigations. Of the three papers which have since appeared dealing with the lithology of western Tertiary formations, none has been by a petrologic expert. The important part played by volcanic ash in these accumulations has only recently been realized. We now know that the Santa Cruz formation of Patagonia is composed entirely, or almost entirely, of ash, while of North American horizons, the Bridger, Washakie, John Day, Mascall, Rattlesnake, a large part of the White River, and probably others not yet investigated, are either in large part or entirely ash. Ash layers have also recently been reported in the

Wind River. But it must not be supposed that normal sediments do not occur. In a recent Bulletin of the American Museum, evidence has been presented to show that the Bighorn and Wind River basins, formerly regarded as lakes, are really structural troughs surrounded by uparched pre-Tertiary rocks, the erosion of which has contributed to the accumulation of fossil-bearing alluvium within the troughs.

Only a few of the more important investigations and explorations of geologic significance which should be attempted by vertebrate paleontologists in the immediate future can be mentioned.

1. The contemporaneity of mammals and dinosaurs in South America should be investigated and an effort made to ascertain more about the affinities of the dinosaurs associated with the Notostylops fauna. The significance of the resemblance of the Notostylops fauna to that of the Puerco can only be determined by greatly increased collections. The occurrence of dinosaur-bearing beds above horizons affording mammal bones is demonstrated conclusively by the photographs published by Santiago Roth. Until the age of the Notostylops fauna is settled we are not justified in separating the Mesozoic from the Tertiary on the basis of dinosaurs alone.

2. The vertebrate fauna of the Fort Union should be increased. Here dinosaurs and Tertiary plants are said to be contemporaneous. At a few localities the Torrejon mammal fauna has been found. It is desirable to ascertain what the relationships of the horizons affording this fauna may be to the dinosaur-bearing beds, and also whether the Puerco fauna which underlies the Torrejon in the type locality in New Mexico may be found elsewhere in areas now regarded as Fort Union. To some extent the problem of the Notostylops beds is duplicated here.

3. The solution of the problems just mentioned necessitates a fuller knowledge of the mammal faunas of the Cretaceous. The fragmentary remains from the Morrison, Belly River, Judith, and Laramie are of little assistance in deciding whether the mammals of the Notostylops beds are, by any chance, Cretaceous in their affinities.

4. A study of Pleistocene non-marine fossiliferous deposits in relation to the glacial stages is much to be desired. The late Professor Calvin's paper on the Aftonian mammal fauna was a step in the right direction. Such investigations may properly be allied with prehistoric archeology. In comparison with European workers, we have done almost nothing with the problem of Pleistocene man in America.

5. The correlation of marine with non-marine beds has already been mentioned. The best efforts of all paleontologists should be concentrated on this most important matter.

6. A discussion of paleogeography based on the migrations of vertebrate faunas with special reference to some of the ideas formulated by Suess and his followers would be a most valuable contribution to geology. It must, however, be free from all suspicion of special pleading, should be based on mammals, land reptiles, and flightless birds, and should take full cognizance both of what is known and what may be legitimately inferred regarding the paleogeography of the late Paleozoic, the Mesozoic, and the Cenozoic from the facts and theories of geology.

7. The mapping according to modern methods of a few of the more important mammal-bearing localities should be undertaken in cooperation with governmental surveys. With the exception of a few White River areas in Wyoming and Nebraska, no detailed mapping of the continental Tertiary has been attempted. Topographic maps do not exist covering the Wind River, Bighorn, Wasatch, John Day, and many other areas studied in great detail paleontologically. No wonder geologists are disposed to question our results, and yet the paleontologist is not to blame. The lack of maps has confined the efforts of the vertebrate paleontologist to the methods of reconnaissance geology.

8. All horizons affording vertebrates should receive careful petrologic study both with respect to the nature and origin of the sediments and the conditions controlling deposition. Reference has already been made to some of the unexpected results attained by the use of the microscope.

9. Finally, the vertebrate paleontologist should remember that geologists are not interested in the purely biological aspects of paleontology. The vertebral formula of *Eohippus* does not thrill them with delight. Why should it? As the sister science of geology, paleontology is not and can never be purely biological, and to the extent that geologic methods, objects, and results are kept in mind by the paleontologist, by just so much will he interest the geologist. Vertebrate paleontologists should strive to produce results which are *geologically* paleontological.

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THE MONUMENT CREEK GROUP[1]

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INTRODUCTION

PREVIOUS WORK

The Monument Creek group is the name introduced by Hayden,[2] in 1869, for the "series of variegated beds of sands and arenaceous clays . . . of various colors . . . and of various degrees of texture" which occur on the Platte-Arkansas Divide along the base of the Front Range in Colorado. Since their first description these rocks have been often referred to, notably by Hayden,[3] Cope,[4] Emmons,[5] Eldridge,[6] Lee,[7] and Darton.[8] Hayden at first considered the Monument Creek group "Modern Tertiary," on the basis of its general appearance and uncon-

[1] Published by permission of the Director, U. S. Geological Survey.
Manuscript received by the Secretary of the Society January 20, 1912.

[2] F. V. Hayden: Preliminary Field Report of the U. S. Geological Survey of Colorado and New Mexico, 1869, pp. 39-40.

[3] F. V. Hayden: Seventh Ann. Rept. U. S. Geological and Geographical Survey, 1874, pp. 32 and 33; Eighth Ann. Rept. U. S. Geological and Geographical Survey, 1876, pp. 36 and 37.

[4] E. D. Cope: Seventh Ann. Rept. U. S. Geological and Geographical Survey, 1874, p. 430.

[5] S. F. Emmons: Denver Monograph, U. S. Geological Survey, no. xxvii, 1896, pp. 38 and 39.

[6] G. H. Eldridge: Denver Monograph, U. S. Geological Survey, no. xxvii, 1896, pp. 252 and 254.

[7] Willis T. Lee: American Geologist, February, 1902, pp. 101-103.

[8] N. H. Darton: American Journal of Science, vol. 20, 1905, pp. 178-180.

formable relations to the underlying Cretaceous strata, but because of the fossil plants found in the group he suggested its equivalence to a portion of the "Lignitic" group. Later, influenced by Cope, Hayden was "inclined to regard it [the Monument Creek group] as Miocene."

In 1874, on the basis of vertebrate fossils, Cope concluded that the age of the Monument Creek group was between Eocene and Pliocene, and was probably Miocene.

The authors of the Denver Monograph pointed out that two divisions, marked by an apparent unconformity, could be distinguished in the Monument Creek, which, nevertheless, they designated a formation instead of using Hayden's name group. Emmons, referring to the fact that the vertebrate remains on which the Miocene age of the beds was based had not been definitely located, suggested that they probably came from the lower division, and that the upper might be Pliocene. Eldridge provisionally accepted Cope's reference of the age of the Monument Creek to the Miocene. In this connection it should be noted that Cope doubtless considered the bones found in the Monument Creek to be White River, which formerly was considered Miocene, but which now is classed as Oligocene.

Darton in 1906 announced the discovery, in the Monument Creek "formation," of Titanotherium bones, "apparently from the upper beds," which he correlated with the Chadron formation of the White River group.

PRESENT WORK

The present writer, in connection with a study of the geology of the Castle Rock quadrangle during the seasons of 1910-'11, found it necessary to separate the Monument Creek group into two formations on the basis of a well-marked unconformity which separates beds of Eocene and Oligocene age. The lower formation is named the Dawson arkose and the upper one the Castle Rock conglomerate. Stratigraphic relationships indicate that the Arapahoe and Denver formations are equivalent to the lower part of the Dawson arkose, and this evidence is paleontologically supported.

The map (figure 1) shows the distribution of the Dawson arkose and the Castle Rock conglomerate, and also of the Denver formation and part of the Arapahoe, the latter taken from the Denver Monograph. The unconformity, on the basis of which the Monument Creek group is subdivided, is finely exposed on Castle Rock, north of the town of that name, and is generally well marked throughout the area, being especially prominent in the bluffs about Castlewood Reservoir, in the vicinity of the settlement of Bijou Basin, southwest of Elbert, and elsewhere. This

boundary in general is easily followed, because of its usual occurrence at the base of prominent cliffs. On the other hand, the base of the Dawson arkose in places can be followed only with difficulty, and in areas of low

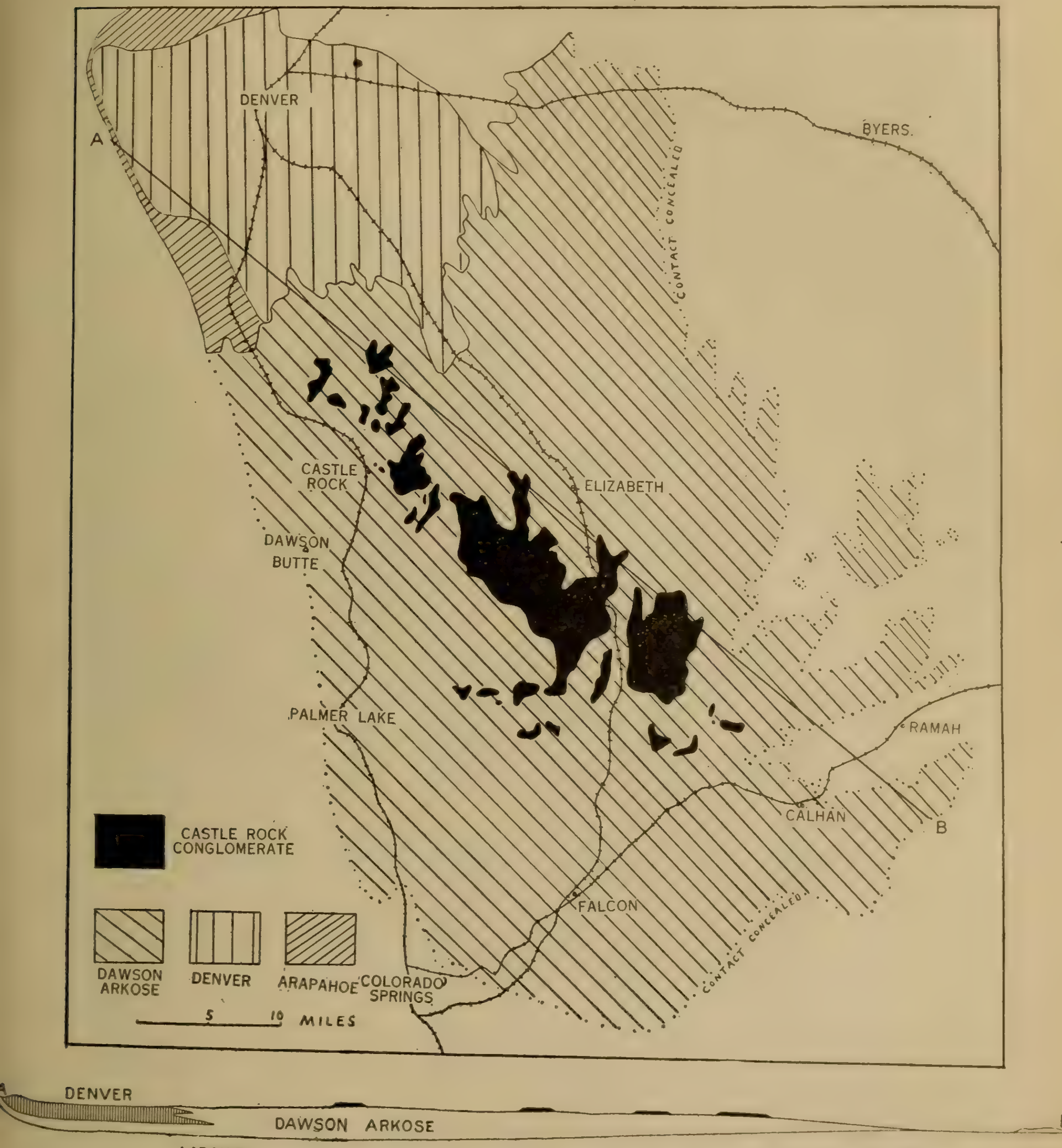

FIGURE 1.—*Map and Section of Tertiary Strata between Denver and Colorado Springs*

relief, as on the plains, the contact is generally concealed by Quaternary deposits, so that its location can only be inferred. But where better exposed, as northeast of Perry Park, in the Castle Rock quadrangle, the

base of the Dawson arkose is marked by a conglomerate lying unconformably on the Laramie formation.

The Castle Rock Conglomerate

The uppermost part of Hayden's Monument Creek group, that part lying above the unconformity exposed on Castle Rock which has been traced throughout the area mapped, is named the Castle Rock[9] conglomerate, from Castle Rock, a prominent hill immediately north of the town of that name. The Castle Rock conglomerate has a maximum thickness of about 300 feet. It outcrops in detached areas on the divides between the tributaries of South Platte River from the vicinity of Elbert to the vicinity of Sedalia, a distance of about 40 miles.

The Castle Rock conglomerate is a massive indurated deposit, which is the remnant of a once larger extent of the formation that has been removed by erosion. It is situated in the south central part of the Denver Basin, where the strata lie almost flat, but, conforming with the pitch of the syncline, have a distinct though slight northward dip.

Everywhere the Castle Rock conglomerate rests on an undulating, eroded surface of the underlying Dawson arkose, and there is an abrupt change in texture of the material from the medium or fine-grained arkose of the upper part of the Dawson to the coarse Castle Rock conglomerate. The bottom of the conglomerate is composed of rounded pebbles, up to several inches in diameter, of quartzite, quartz, red sandstone, gneiss, and granite, and of larger, usually irregular, blocks of rhyolitic rocks. These are imbedded in a finer-textured matrix of quartz and feldspar. The conglomerate is remarkably persistent in its general features, yet it is of variable texture, coarser and finer-grained phases being intimately associated, and in places the rock is an arkosic sandstone, which, however, is streaked with variable conglomeratic lenses.

A number of Titanotherium bones have been found in the Castle Rock conglomerate at various localities. Especially noteworthy is a collection from the plateau east of Elbert, including a well-preserved lower jaw, with teeth identified by Mr. J. W. Gidley, of the U. S. National Museum, as *Titanotherium trigonoceros* (?). These bones correlate the Castle Rock conglomerate with the Chadron formation, the name given by Darton to the "Titanotherium beds" which constitute the lower formation of the White River group of Oligocene age.

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[9] Castle conglomerate was suggested by Willis T. Lee for this formation, but the name is not admissible because of prior usage.

Willis T. Lee: Geology of the Castle Rock area. American Geologist, February, 1902, p. 103.

The Castle Rock conglomerate is an outlying erosion remnant of a former greater sheet of the White River group, which is typically developed in southwest South Dakota and west Nebraska. The source of the components of the conglomerate undoubtedly was the rocks of the Front Range, the material apparently being laid down as outwash and fluviatile deposits following a period of uplift of the mountains to the west.

The Dawson Arkose

That part of Hayden's Monument Creek group which lies below the unconformity at the base of the Castle Rock conglomerate is named Dawson arkose, from Dawson Butte, situated 7 miles southwest of Castle Rock. The Dawsosn arkose outcrops on the Platte-Arkansas divide, between Denver and Colorado Springs, and extends eastward from near the base of the mountains to the valleys of Kiowa and Bijou creeks, a distance of 40 or 50 miles (see figure 1).

Conforming with the general structure of the southern part of the Denver Basin, the Dawson arkose constitutes part of a northward pitching unsymmetrical syncline. On the west the beds locally form part of the foothills and dip eastward at an angle of about 45 degrees. This dip rapidly flattens out, and the westward inclination at the opposite end of the basin is very gentle. In the vicinity of Palmer Lake and for several miles north and south of that place, where the arkose abuts directly against the granite of the mountains, the contact is faulted.

The Dawson arkose has a maximum thickness of about 2,000 feet. It is thicker on the west, toward its source in the mountains, and thins out eastward.

The formation is a complex aggregate of vari-colored and vari-textured conglomerate, sandstone, shale, and clay, derived from the rocks of the Front Range and deposited under a variety of continental conditions. Sandstones comprise the greater part of the Dawson arkose. They are medium to coarse-textured arkosic grits, composed chiefly of quartz and feldspar derived from the Pikes Peak granite and associated rocks. Beds and lenses of conglomerate occur throughout the formation, but they are more common in the lower part and nearer the mountains, where a basal bed is well developed, consisting of pebbles of granite, quartz, quartzite, chert, and occasional fragments of limestone and sandstone, from the foothills strata, in an arkose matrix. There are also local bodies of clay, as at Calhan, where a deposit of commercial importance is being worked.

There is pronounced irregularity in the arrangement and sequence of the deposits which constitute this formation. Cross-bedding is common.

There are abrupt changes in composition and texture of the rocks and a number of local unconformities are exposed. One of unusual prominence occurs near the top of several buttes in the vicinity of Larkspur and Greenland. Another unconformity, exposed on Dawson Butte, is at the base of the rhyolitic rocks, which lie upon an undulating surface of arkose. But in no instance has fossil evidence been obtained of the age of the beds immediately overlying and underlying these unconformities, and it should be borne in mind that unconformities in continental deposits are common.

Rhyolitic rocks, chiefly if not all tuff, were extravasated on an uneven surface of arkose in the extreme upper part of the Dawson. Remains of these rocks cap a number of buttes, which are prominent features of the topography between Castle Rock and Palmer Lake. (Not shown on the map.) In the greater part of the area the beds above the rhyolitic rocks have been removed by erosion, but four miles southeast of Castle Rock the latter are separated by 20 to 30 feet of arkose from the overlying Castle Rock conglomerate, in which there are large fragments of the igneous material.

Silicified wood occurs abundantly in the Dawson arkose. A number of leaves have been collected from several localities and a few fragments of bones have been found.

Bones from the Dawson arkose were obtained by the writer in only one place in the southwest one-quarter of section 2, township 14 south, range 65 west, 9 miles east of Colorado Springs, at an horizon estimated to be about 600 feet above the base of the formation. These bones were found on a hill about 100 feet above the bed of a dry creek, apparently in the immediate vicinity of the rocks in which they were entombed. The collection was examined by Mr. J. W. Gidley, of the U. S. National Museum, who recognized dermal plates of a crocodile and a mammalian bone. Concerning the latter, Mr. Gidley reports:

"The one mammal bone in the collection is the distal end of a tibia, which, while not generically determinable, is characteristically creodont, and indicates a rather highly advanced species of this group. The fore and aft concavity of its articular face, together with the considerable development of a median ridge, denote a specialized type of hind foot leading toward the true carnivores. From our present knowledge of the creodonts such a type could not be older than Wasatch."

The leaves listed below, determined and in part collected by Dr. F. H. Knowlton, are stated by him to be "undoubtedly Denver in age." It will be observed that they come from the lower 500 feet of the arkose. Other smaller lots of leaves, also referred to the Denver, have been obtained

from the lower part of the Dawson arkose in the vicinity of the towns of Monument and Sedalia.

[No. 5837] Section 11, township 12 south, range 62 west, 1 mile southwest of Calhan, Colorado; estimated 300 feet above top of Laramie.

Cornus studeri ? Heer of Lesq.
Palmocarpon commune ? Lesq.
Palm, Sabalites ? sp.
Populus nebrascensis ? Newb.
Ficus, type of *F. planicostata* Lesq.
Vitis olriki ? Heer of Lesq.
Artocarpus ? sp.
Ficus latifolia ? Lesq. Fragment.
Ficus sp.
Sapinlus ? sp.
Age, Denver.

[No. 5831] Section 3, township 14 south, range 65 west, 9 miles east of Colorado Springs, 400 feet above top of Laramie.

Ficus sp., type of *F. trinervis* Kn., but not the same.
Cyperacites ? sp.
Fungus (genus ? parasitic on *Cyperacites* ?) sp.
Geonomites tenuirachis Lesq.
Flabellaria eocenica Lesq.
Gigantic leaf, genus ? No margin.
Ficus tiliæfolia Al. Br.
Ficus sp., type of *F. planicostata* Lesq.
Pteris erosa Lesq.
Age, Denver.

[No. 5835] Section 3, township 14 south, range 65 west, 9 miles east of Colorado Springs, 500 feet above top of Laramie.

Platanus rhomboidea Lesq.
Cinnamomum affine ? Lesq.
Ficus spectabilis ? Lesq.
Rhamnus goldianus ? Lesq.
Ficus sp., new. 5-ribbed, large.
Berchemia multinervis.
Palmocarpon commune ? Lesq.
Age, Denver.

From a higher horizon, estimated to be about 1,000 feet above the base of the Dawson arkose, the following collection of leaves was obtained, concerning which Dr. Knowlton makes this statement: Lot No. 5836, "so far as I am able to tell, appears in large measure to be new; and, such being the case, it is difficult to place it. It is obviously not Laramie, nor is there apparently a single form that is found in the beds referred to the Denver. In some ways it slightly suggests the Green River, but this is too indefinite to be of much use."

[No. 5836] List of plants from cut at railroad crossing 1 mile southwest of Falcon, Colorado; estimated 1,000 feet above top of Laramie.

Asplenium sp., new.
Hemitelia ? sp., new.
Pteris ? sp., new ?
Quercus sp., new.
Ficus ? New ?
Several fragmentary dicotyledons.

These, with the bones, are all the determinable fossils that have been reported from the Dawson arkose, and it should be observed that the collections have been obtained from the lower part of the formation. The flora from the vicinity of Falcon, occurring in about the middle of the arkose, is distinctly different from the Denver flora, and it is quite probable that future discoveries of fossils will prove the presence of higher Eocene groups in the Dawson arkose. Yet as a whole the arkosic deposits constitute a distinct lithologic unit which can not readily be subdivided.

It is evident that the Dawson arkose, together with its associated unconformities, represents the time between the Laramie and the Oligocene. To what extent the later Eocene is represented by the upper part of the arkose remains to be determined. Part of the Eocene no doubt is represented by the unconformity at the base of the Castle Rock conglomerate.

Relations of the Dawson Arkose to the Denver and Arapahoe Formations

The stratigraphic relations of the Dawson arkose to the Denver and Arapahoe formations, which lie in close proximity south of Denver, are generally concealed by a cover of Quaternary deposits, so that actual conditions are obscure. It is not claimed for the recent work that final correlations have been established; but, nevertheless, previously unsuspected relationships are indicated.

Approaching the geologically mapped part of the Denver Basin from the south, where detailed work had not previously been done, it was found that the lower part of the Dawson arkose seems to pass along the strike into the Arapahoe and Denver formations; that the Dawson and Arapahoe can not be separated lithologically, even at the type locality of the Arapahoe, on the bluffs of Willow Creek; and that the Denver and Dawson apparently merge into each other, or interdigitate, layers of arkose typical of the Dawson being found, in a gulch 3 miles northeast of Acequia, intercalated in andesitic Denver material. These conditions

indicate that the Arapahoe and Denver are equivalent to the lower part of the Dawson arkose. The marked difference in lithology between the andesitic Denver and the arkosic Dawson may be accounted for by the geographic distribution of the rocks which supplied the sediments, the arkose being derived from the Pikes Peak granite and associated rocks, whereas the Denver formation was derived, apparently simultaneously, from a local source of andesite.

In the Denver Monograph, Cross pointed out the presence of non-volcanic material in the Denver formation in the southern part of the area reported on by him; but, since the "Monument Creek" was believed to be of Miocene age, the equivalency of part of it to the Denver formation was not suspected. Abrupt changes in material from andesitic to arkosic are of common occurrence at the southern end of the Denver formation, and it should be observed that such contacts may mark only local unconformities, which are of frequent occurrence in continental deposits.

The relations of the Dawson, Arapahoe, and Denver formations suggested by the stratigraphy are borne out by paleontologic evidence. A number of Ceratops bones have been found in the Denver and Arapahoe formations; and, although the writer has not found any in the Dawson, Emmons states[10] that Professor Marsh observed vertebrate fossils characteristic of the post-Laramie in Monument Park, which is 8 miles north of Colorado Springs. This observation is important, for the lower part of Hayden's Monument Creek is the only post-Laramie formation in Monument Park; and, although the vertebrates observed by Marsh are not named, the only ones characteristic of the "post-Laramie," as that term is used in the Denver Monograph, are *Ceratopsia*. This evidence implies the correlation of the lower part of the Monument Creek of Hayden (the lower part of the Dawson arkose) and the "post-Laramie" of the Denver Basin (the Arapahoe and Denver formations). The evidence of the plants is corroborative, for, as already mentioned, Dr. Knowlton states that the leaves from the lower part of the Dawson arkose, listed above, are undoubtedly Denver in age.

In the light of present knowledge, therefore, it seems plausible that the Arapahoe and Denver formations are the equivalent of the lower part of the Dawson arkose.

Correlation

Precise correlation of the Dawson with other Eocene deposits of the Rocky Mountain region outside of the Denver Basin in the present state

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[10] Denver Monograph, p. 31.

of knowledge can not be made. And in this connection it should be emphasized that, notwithstanding the detailed work that has been done, exact correlations of many of the early Tertiary formations are not yet possible. A large number of stratigraphic sections and fossil collections prove that the early Tertiary history of the region was complex. There is evidence of local uplift in different areas at different times, and the consequent varied topographic conditions gave rise to diverse, isolated, continental deposits. Moreover, changing environment must have had its effect on animal and vegetable life, so that the varied conditions existing at the same time in different parts of the region may have made it possible for different forms of life to exist simultaneously in different areas. These factors complicate the task of correlation and in a measure account for the slow progress that is being made in solving early Tertiary stratigraphic problems in the Rocky Mountain region.

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POSTGLACIAL EROSION AND OXIDATION[1]

BY GEORGE FREDERICK WRIGHT

(Presented before the Society December 29, 1911)

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Erosion in the Valley of the Great Lakes

Northern Ohio furnishes unrivaled opportunities for estimating the amount and rate of erosion since the final withdrawal of Wisconsin ice from that region. The watershed between the basin of the Great Lakes and that of the Mississippi Valley is nowhere more than 100 miles south of Lake Erie, averaging not more than 50 miles. The elevation of the cols through which the drainage passed into the Mississippi Valley, as the ice retreated northward from the watershed, ranges from about 300 feet above Lake Erie, at Warren, Ohio, and Lodi, to 200 feet at Fort Wayne, Indiana. Of these, the col at Fort Wayne is most important in regulating the level of the temporary glacial lake which was formed north of the watershed. The occupation of this col by the drainage stream was so long that a well-defined shoreline, 200 feet above Lake Erie, can be traced across Ohio for hundreds of miles. This affords an excellent starting point for forming estimates of post-Glacial erosion; for, while south of the watershed the problems are complicated by the effect of the streams during all the period which elapsed while the ice was retreating from the southern boundary to the watershed, north of this watershed there is no such complication. The entire amount of work accomplished since the opening of the channel at Fort Wayne and the formation of the 200-foot shoreline south of Lake Erie, is everywhere open to inspec-

[1] Manuscript received by the Secretary of the Society January 9, 1912.

tion. Even a cursory examination of these streams can not fail to impress the observer with the small amount of work which has been done by them; while in the case of Plum Creek, in Oberlin, an unusual opportunity has been offered for definite calculations.

Plum Creek is a branch of Black River, draining an area of 25 or 30 square miles. At Oberlin the elevation of its bed is 800 feet above sea-level, or approximately 235 feet above Lake Erie, which is distant 10 miles in a direct line. The descent from Oberlin to the falls in Black River at Elyria, 8 miles distant, is 100 feet, or 12 feet to the mile. But the bottom of its trough averages 17 feet below the general level of the country. This trough is entirely one of erosion, the original stream having begun its work 250 feet above the level of Lake Erie and 50 feet above the 200-foot shoreline, which is 5 miles to the north. The region is so deeply enveloped in till that the underlying rock is nowhere exposed in the bed of the creek. The entire trough has been eroded in till, so that there is no complication of rock barriers requiring an indefinite time for removal.

A section of this trough 5,000 feet long, where it had been least modified by artificial interferences, was found to average 400 feet in width and 17 feet in depth, showing that a total amount of 36,000,000 cubic feet of till had been removed by the stream from this section since the beginning of its flow.

Opportunity to obtain an approximate estimate of the rate of erosion effected by the stream was fortunately furnished by the town's taking possession of its trough for a reservoir and their turning the drainage around through an open ditch, 14 years ago. We have thus been able accurately to determine the rate at which this stream removes the material under the new conditions produced by this change in its course. On measuring a section of this new channel, 500 feet long, and noting from year to year its enlargement, it was ascertained that the original ditch, which was 21 feet wide at the top and 10 feet at the bottom, had in 12 years been enlarged by the erosion of the stream to a width of 51 feet at the top and 17 at the bottom, showing that, from this 500-foot section, 8,450 cubic feet of material had been removed every year.

But, to make the estimate applicable to the older section of 5,000 feet, where the erosion represented the entire work since the opening of the Fort Wayne outlet, it was necessary to go into this 5,000-foot section and measure the length of the sections where the present stream is impinging against the original till bank and eroding it under conditions similar to those existing in the 500-foot cut-off. As will be seen on slight reflection, in the 500-foot cut-off the stream is acting directly upon 1,000 feet

of freshly exposed banks of till, but upon the 5,000-foot section the present meandering of the stream permits it to touch the till bank only here and there. But it was found on measurement that, of the 10,000 feet of till banks originally exposed to the action of the stream in this 5,000-foot section, 1,600 feet are still exposed to it in its meandering. On the supposition that in these exposed places the erosion is proceeding at the same rate per foot as in the 500-foot cut-off, we arrive at the conclusion that the annual erosion in the 5,000-foot section is 13,568 cubic feet.

That the rate of erosion in these exposed places is approximately equal to that in the 500-foot cut-off is evident from the fact that the water in its curves impinges against the banks in substantially the same way and with substantially the same force in the one place as it does in the other; and, furthermore, while we have not definitely measured the amount of erosion in the 5,000-foot section, we do know that great changes have been produced by the erosion there during the last few years. Large trees standing on the top of the bank have in several cases been undermined and toppled over into the stream and the top of the bank pushed back beyond the area on which they were firmly rooted.

Dividing 34,000,000 feet of material, the total amount removed from the 5,000-foot section, by 13,568, the number of cubic feet estimated to be annually removed by the stream at the present time, we find that the whole work would be accomplished in 2,505 years—a result so startling that we are compelled to study carefully the modifying conditions under which the erosion has proceeded. Some of these we shall find to be retarding in their effect, while there are others that will be accelerating. The principal retarding conditions are connected with the existence of the forests which prevailed over the area for an indefinite period of time previous to the advent of civilized man a hundred years ago. While we have no definite calculation on which to base an estimate of this retarding influence, I have thought it safe to assume that it would not be more than tenfold, so that the erosion in the forest would accomplish as much in 1,000 years as would be accomplished under present conditions in 100 years. This would extend the time to 25,000 years.

But there are various considerations which would cut down this estimate, the chief of which is that the present exposures to erosion in the 5,000-foot section are at a minimum in their extent. Originally the conditions were identical with those produced in the cut-off around the reservoir; that is, the creek was a narrow stream eroding from both banks throughout the entire distance. As the stream enlarged its trough and began its meanderings, the exposures to erosion became less and less, but the average would be twice those of the present time, thus reducing the

period necessary to effect the observed results to 12,500 years, which probably is not far from correct.

There are, however, some other modifying causes on both sides which must be considered. In the cut-off around the reservoir the shortening of the course has slightly increased the gradient of the stream through that district. This would evidently increase its efficiency. But, on the other hand, the original gradient (about 12 feet to the mile) with which the stream began its work would have been the same as that in the cut-off at the present time. Again, the retarding influence of the forests would not begin until some time subsequent to the beginning of the erosion. Probably, also, the precipitation in that early period was much larger than now, thus increasing the early rate of erosion. These things may therefore be permitted to balance each other so nearly that the withdrawal of the ice from the northern part of Ohio is to be measured by *thousands* of years rather than by *tens of thousands,* fully sustaining the general impression which is made upon the observer almost everywhere in the entire section of country.

As this region is 300 miles south and west of the Mohawk and Saint Lawrence valleys, it is evident that the opening of the drainage lines, which would permit the Niagara River to begin its erosion of the gorge above Lewiston, must have been considerably later—probably two or three thousand years later. This we should infer from the size of the various shorelines or lake ridges which occur south of Lake Erie, and from our general impression of the rapidity with which the ice-front retreated. At any rate it is impossible to extend the age of Plum Creek sufficiently to be consistent with a date of thirty or forty thousand years for the beginning of the erosion of Niagara. There must be some error in the data from which those calculations have been made which give tens of thousands of years to the age of the Niagara gorge.

A similar conclusion follows from my observations upon the lateral erosion at the mouth of the Niagara gorge, detailed in the Popular Science Monthly for June, 1899, and the American Geologist, volume 29, pages 140-143, and summarized in the fifth edition of the Ice Age in North America, pages 548-552.

Stream Erosion South of the Saint Lawrence-Mississippi Watershed

In considering the effects of stream erosion in front of the continental ice-sheet in the channels which opened freely to the south, we have to bear in mind the enormous floods of water set free by the melting ice.

In the Missouri River[2] we have direct evidence, in the boulders which were carried to Tuscumbia, 60 miles up its southern tributary (the Osage River), that there were annual floods, in the latter part of each summer during the closing stage of the Iowan epoch, rising to a height of 200 feet. Floods to this extent are also made to seem credible from the amount of ice which the sun would be capable of melting over the glaciated area tributary to the Missouri River. Floods of similar dimensions must also have poured through troughs of the Ohio and Alleghany rivers. So enormous were these floods that it is difficult to set limits to the work accomplished by them. Wherever they or their tributaries were eroding channels they would effect results which can not be measured at all by the work accomplished by present comparatively insignificant streams.

On the other hand, in the Alleghany Valley there are certain features of deposition, pointed out by Prof. E. H. Williams, which indicate an entirely different interpretation from that ordinarily given of the high-level gravels which border the Alleghany River throughout its entire middle and lower course. Mr. Williams has pointed out that these deposits uniformly occur where a tributary glacial stream came in with sufficient force to throw coarse gravel to a high elevation on the other side, as at Kenerdell, where tributary streams from the melting ice-front near by came into the Alleghany River at right angles, through Scrub Grass Creek, with power sufficient to push gravel up 300 feet upon the opposite side. Lower down the stream, beyond the direct influence of glacial tributaries, the high-level gravel terraces occur below bends in the trough of the river where the direct action of the swollen current would throw gravel on and over the rock shelves which furnished the most direct outlet for the rushing torrent at that elevation.

In detailing the phenomena at Kenerdell,[3] I had shown the impossibility of considering this gravel deposit as a remnant which had existed during the entire period demanded for the rock erosion of the gorge, but had supposed that it did involve the filling of the gorge with glacial gravel and the subsequent erosion of the trough. But Mr. Williams' explanation is more credible. The plunging current from the glacial border, coming down through the trough of Scrub Grass Creek, kept the trough of the Alleghany scoured out and threw the material upon the opposite bank. Below this point the high-level gravels which I had noted, at Gates Ferry, Emlenton, Bradys Bend, Orrsville, Kittanning, Tarentum, Springfield post-office, and Verona, besides numerous intervening places, are accounted for by the shifting angles at which the glacial tor-

[2] See American Geologist, vol. 33, April, 1904, pp. 205-222.
[3] See American Journal of Science, vol. 47, March, 1894, p. 175.

rents impinged on the sides of the deeply eroded rock channel. At Alleghany City and below Pittsburgh the same forces were at work, modified by the entrance of the Monongahela River from the south and Beaver Creek from the north. By attention to these considerations these high-level terraces can for the most part be eliminated from the evidence implying a great antiquity to the closing scenes of the Glacial period in the Ohio Valley.

It is difficult for the imagination fully to comprehend the conditions attending the closing stages of the Glacial epoch in the upper Alleghany Valley, for down this valley there escaped the drainage from northwestern Pennsylvania, western New York, and a good part of Ohio drained by French Creek and the Beaver, producing a deep, torrential stream whose surface was covered with bergs and smaller masses of floating ice dropped from more than 100 miles of ice-front. Two different forces were at work tending to deposit high-level gravel and at the same time to keep the main channel well scoured and free from sediment. I quote from a private communication from Professor Williams, after the completion with ample assistants of his survey of the region during two seasons:

"1°. The abnormal amount of berg material from so long a front would not go sailing quietly down the stream, but would go grounding on the margins, heaving and tossing in midstream, choking up narrow passages to form temporary ice dams, which would raise the level of the flood till the pressure was sufficient to break the dam, when away the mass would go on a wave that would send a part of the ice on high shelves, where it would strand above the average level. I have seen in our little stram here in Woodstock [Vermont] such a wave to carry debris 30 feet above stream level. This spring [1910] the ice will leave a deposit of (average) 6 inches deep up to 10 feet above the average level and the greatest thickness of the ice pile was only 12 feet.

"The overwash from the glacier carried both free gravels and gravels frozen in masses of ice. The carrying power of ice has not been as fully considered as it should be. Ordinary freshets in Vermont streams, with break-up of ice in spring, show that ice 2 and 3 feet in diameter, frozen down to the stream bottom, will lift and carry when the break-up comes stones up to one ton weight. I have an instance of such a stone left, with gravel heaps, in a mowing 50 feet from the water's edge, and every year the Vermont farmers have to clear away gravels with cobbles weighing anywhere from a pound to 50 pounds. We can now see that the overwash of a glacier would carry everything of small enough mass to be influenced by the force of the current. This accumulation would be of sands and clean gravels of certain size and sands and boulders frozen in ice, the latter being of many times the size.

"A current of 1 foot per second will carry sands. The transporting force of a current varies as the sixth power of the velocity. A current 3 feet per second or 2 miles per hour will move stones 3 ounces in weight (hen's egg); a torrent[4] of 20 miles per hour will carry fragments of 100 tons weight.

[4] See Le Conte's Geology, pp. 19 and 20.

"Now, this is merely a torrent carrying clean stones. If we have these stones mingled with ice (not frozen to them) the carrying power of the ice aids the current, as the torrential power of the water drives ice and stones together wherever the current reaches to the bottom of the trough.

"If we in addition consider the ice actually frozen to the stones we shall see that there is nothing to prevent the statement that gravels of any size may be transported in a glacial overwash.

"2°. A second deposit due to ice, which would also be stratified, would occur when the current, which is always more sinuous than the channel, would strike against a gentle slope and force the large cakes with their high momentum sliding up the slope. This is the case of sporadic gravel patches along the Juniata, which are over 100 feet above present water level, while the average of the gravels is but 80 feet above that level.

"3°. Wherever a sudden widening of the valley formed a cove, across which the current did not flow, an eddy would form, and into the cove would drive the bergs, circling in a path influenced by the contours of the sides and dropping their burden from the grinding action of the mass rather than its ablation. This would not be usual iceberg clay formed in still water, but a more or less stratified mass. A very good example is Fountain Hill, a part of South Bethlehem, Pennsylvania, which is an eddy hill formed of gravels and huge masses of rock. One Medina mass was 11 feet long, 5 wide, and 3 thick. These huge stones were in the core of the hill, and around them were stratified gravel, rising over 100 feet above the present level of the Lehigh.

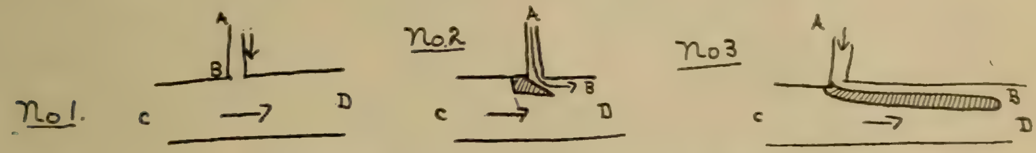

FIGURE 1.—*Diagram illustrating the Effect of torrential Affluents on the main Stream*

No. 1 is the state of affairs before the trouble begins. A-B is a torrential side affluent into C-D, a stream with lower velocity, and with the checking of the current of A-B there forms a sedimentary deposit which forms a ridge in the bed of the main stream.

"One thing noticeable in the Warren [Pennsylvania] gravels was the infrequent, but constant presence of large cobbles in strata of finer gravels and sands, and in a small lenticular stratum of fine quicksand was found a mass of native copper, or rather a nugget, about 5 inches long and a little thicker than the thumb. Considering the difference in size, and still greater difference in specific gravity, I felt that only floating ice could thus mix things.

"4°. The accumulations of debris dropped by the ice driven up the hillsides by momentum or sporadic dams would be, under the influence of a changeable current, diverted by lodgments of ice that did not readily dislodge, so that such a current deflected transversely to the general direction would sweep away these sporadic accumulations into still water and form a pile out of the general direction of sedimentation.

"5°. Then comes the usual case of a deposit in the form of a bar wherever the current swept round a hill; but such a deposit would run up the hill and not be isolated from it, as would be the case with the 'eddy' hills above noted.

"6°. Wherever a side affluent came in at a wide angle, there would be a tendency to form an eddy. The general case here is like a long eddy hill.

"There is one thing I have tried to keep in mind, and that is that the Alleghany deposits are the remainders of the sediments deposited before the ice reached that river, as modified by the actual presence of the ice, which probably did no work in the valley bottoms, owing to the great depth and buoyancy of the water and as further changed by the action of the retreating glacier.

"In every case of an abnormal form or situation of a deposit I have tried to imagine how the forces must have acted, and the first thing was to get the

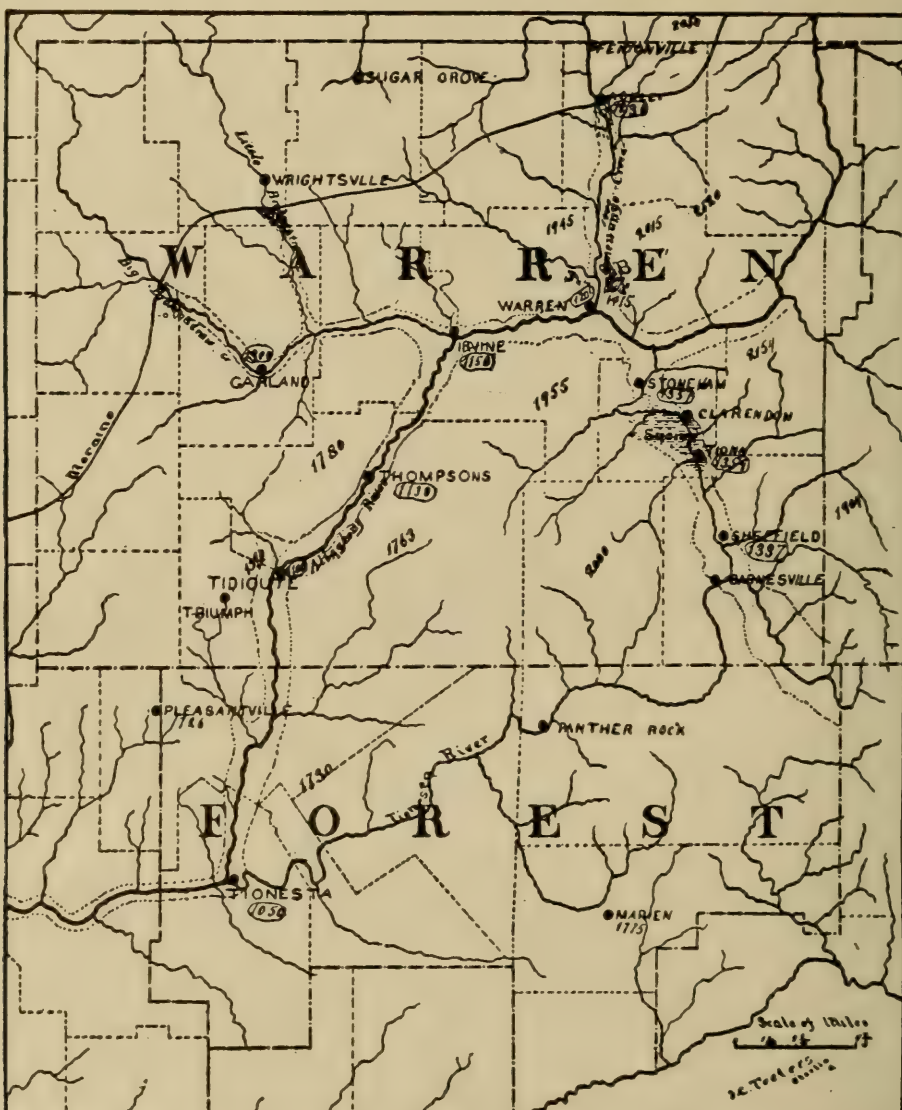

FIGURE 2.—*Map of the Vicinity of Warren, Pennsylvania*

depth of water and direction of flow. At one time there were two forces acting near Warren in opposite directions—the first, from upstream, filling in the north end of the valley; the second, from the Brokenstraw, filling the other end. These met about half way between Warren and Irvineton. At that time I think the col which formed the highest water and made a flow past Clarendon had not been degraded, but after it had been cut down there began the action of the forces that finally made the present Alleghany Valley.

"At Warren the drive-pipes of oil wells in many cases have been driven through the gravels from a surface hundreds of feet above the present level of the river to a depth 20 feet below the present water level, showing that the Conewango Valley was degraded before the gravels were deposited, and the river now flows on 20 feet of those gravels, and so 20 feet above the preglacial level of the valley. There is no rock shelf there, but an aggraded valley, with bed 20 feet above its preglacial level."

FIGURE 3.—*Topography East of Warren, Pennsylvania*

A is a hill, which deflected the glacial stream down the Conewango; m^{I}, m^{II}, m^{III}, m^{IV}, and x^{I}, x^{II}, x^{III} are places where wells have been sunk, revealing gravel as in figures 4 and 5. These high, level gravels at Warren are shown to be deposits of the Glacial age in a valley that was entirely preglacial. The force of the current was such that, while leaving these gravels in the lee of hill A, it scoured them all away from the south side of the Conewango.

SIGNIFICANCE OF ESKER TERRACES

The existence of "esker" terraces has also led, as I believe, both in this country and in Europe, to a great exaggeration of post-Glacial time. Two such series of terraces have come under my observation in Ohio, namely, in the River Styx, in Medina County, between Seville and Wadsworth, and in the Mohecan River, in Wayne County, in the vicinity of Wooster. In both cases these streams flow southward from the water-

shed and occupy wide preglacial channels about 300 feet below the general level of the country. In both cases the bottom of the troughs are about a mile in width and as level as a floodplain, but in both cases the trough is bordered upon the west side by gravel terraces from 100 to 200 feet above the present level of the stream. The readiest explanation of these terraces is that they are composed of gravel deposited by torrents from the melting ice, which flowed at that level between stagnant ice which filled the valley and the sides of the preglacial rock gorge. Russell has published photographs of a stream similarly situated, held at a level 2,000 feet above the sea, between the Malaspina Glacier and the flanks of Mount Saint Elias. Emerson[5] has thus given a rational explanation of

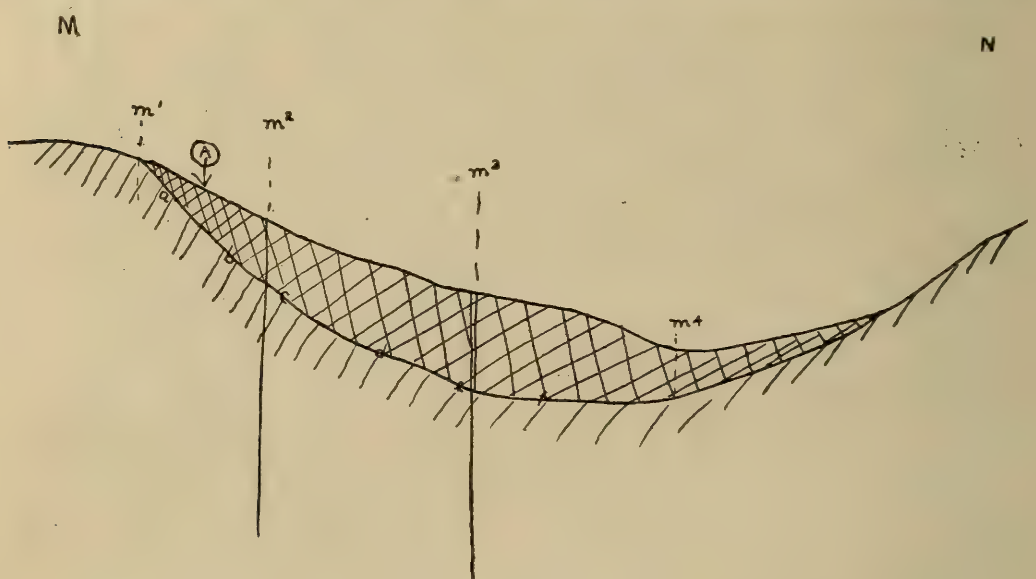

FIGURE 4.—*Gravel Accumulations along Section N-M in Figure 3*

A, b, c, d, e, f, marks the contour of the preglacial valley

many of the high-level terraces bordering the Connecticut River, which had formerly been explained by Professor Dana as the results of incredible floods in the open trough of the river. An interesting feature in the Killbuck, near Wooster, Ohio, is the occurrence of a deposit of till from 15 to 20 feet in thickness which has been pushed over this terrace without disturbing its bedding. The elevation is here 200 feet above the floodplain of the river. It is interesting to remark, also, that both in the "esker" terrace of the Styx and in that of the Killbuck, paleolithic implements have been reported, but on evidence less exact than is necessary to make them available for public discussion (see plate 11, figures 1 and 2).

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[5] B. K. Emerson: Geology of Old Hampshire County, Massachusetts. U. S. Geological Survey, monograph xxix.

FIGURE 1.—SECTION OF THE ESKER TERRACE ON THE KILLBUCK, SOUTH OF WOOSTER, OHIO
Photo by Prof. J. J. Crumley

FIGURE 2.—ESKER TERRACE COVERED BY 15 FEET OF TILL
Photo by Prof. J. J. Crumley

ILLUSTRATIONS OF OHIO ESKER TERRACES

These facts become important in modifying the calculations which have been made concerning the age of the terraces in the valley of the Somme, and in those of other streams in northern France and southern England where paleolithic implements have been found. It is by no means necessary to suppose, as has been generally done, that the valley of the Somme, for instance, was first filled with gravel to the height of the 90-foot terrace and then the material eroded by the present small stream from the area occupied by the present broad floodplain. In discussions of the problem in the valley of the Somme, both Dr. Warren Upham[6] and Prof. E. B. Tylor[7] have maintained that these terraces were merely marginal accumulations of gravel, but neither of them has taken

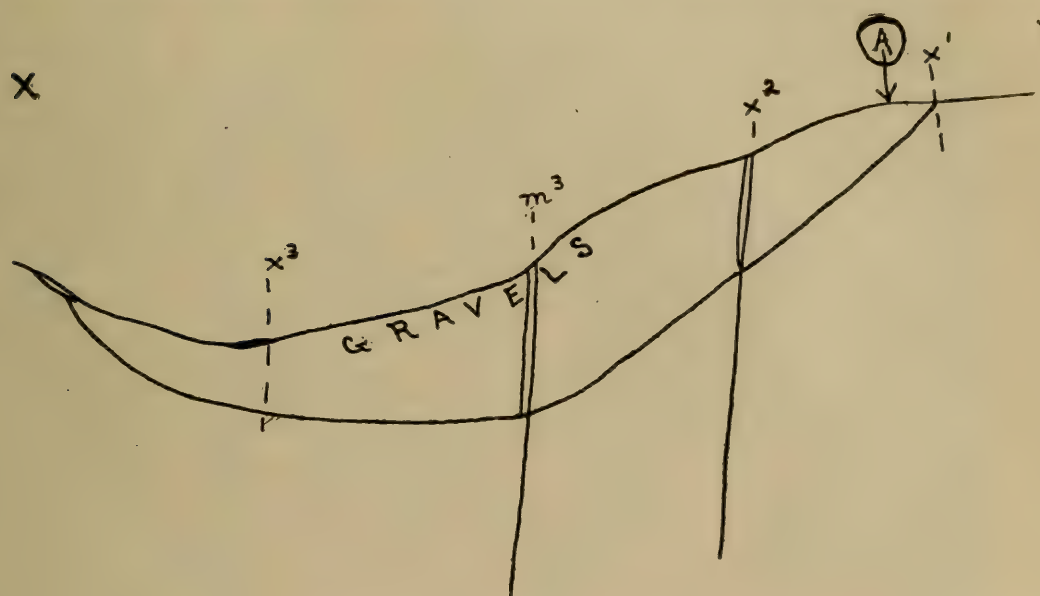

FIGURE 5.—*Section X-Y of Figure 3*

Showing the depth of gravel which had accumulated in the original valley, whose bottom is indicated by the lower line

advantage of the probable existence of stagnant ice in the valleys acting as a temporary barrier to determine the course of the currents which deposited the gravel.

Other more general problems present themselves in the broader areas of the glaciated region nearer the center of the Mississippi Valley. Over much of this area, as the glacial boundary is approached, the supply of drift was diminished, so that it was less and less able to fill up and therefore to disguise the inequalities caused by preglacial erosion. As good

[6] American Geologist, vol. xxii, pp. 350-362.

[7] Proceedings of the Geological Society, London, vol. xxiv, pp. 103-128; vol. xxv, pp. 57-100.

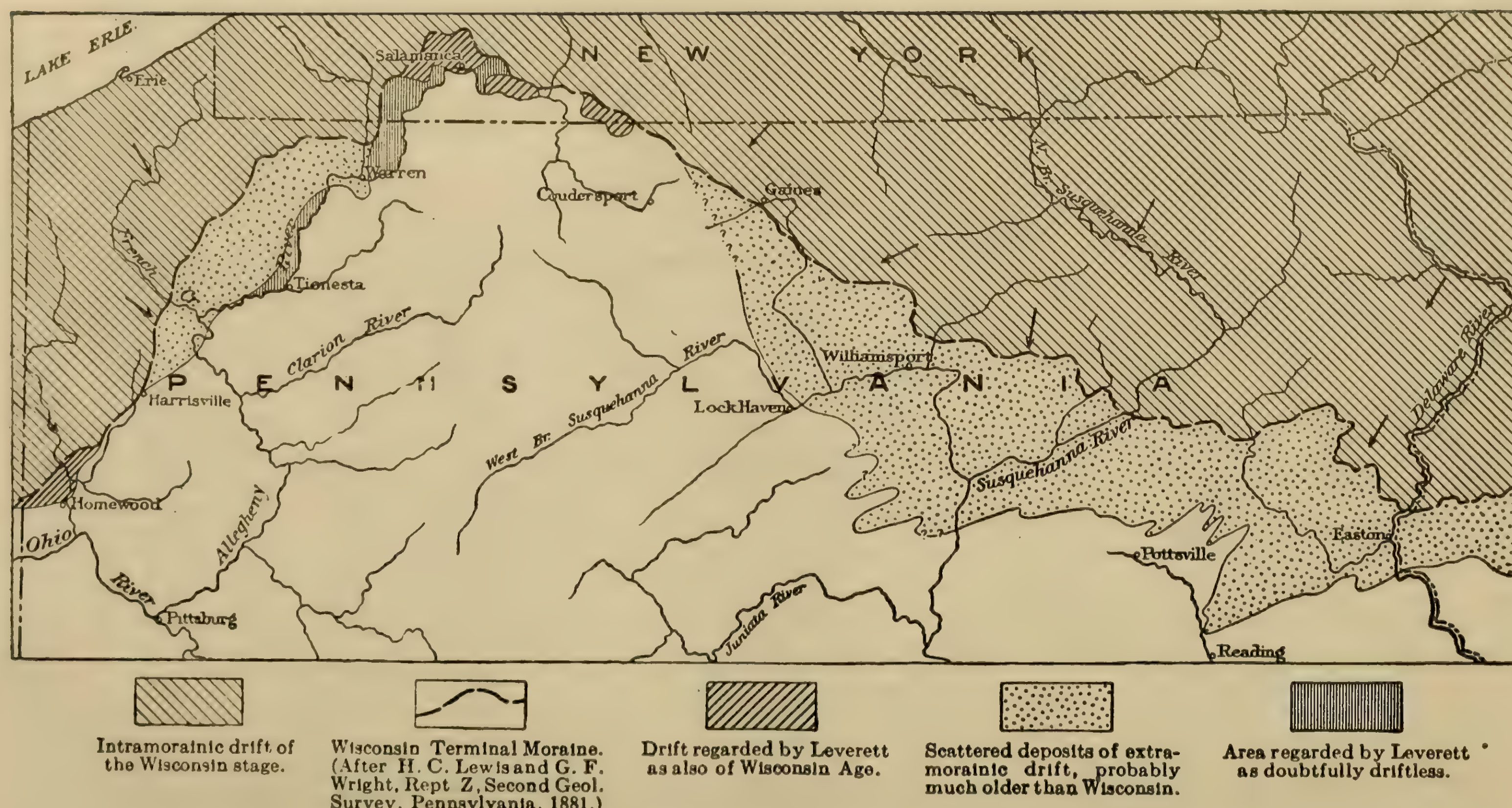

FIGURE 6.—*Map showing Distribution of glacial Deposits of Pennsylvania and adjoining Portion of New York*

Arrows indicate direction of glacial striæ. Scale, 1 inch = approximately 40 miles. Compiled by Wm. C. Alden, 1901. (From United States Geological Survey)

a place as any to illustrate this point is in the area between the Illinois and Mississippi rivers extending from Galesburg northeast along the line of the Burlington and Missouri Railroad. For a long distance this is a tableland from 300 to 350 feet above the rivers mentioned on either side. The glacial deposits over this area consist of a pretty uniform capping of loess, 10 or 15 feet in thickness, overlying till of about the same thickness on the average, but deepening to a hundred feet or more in the depressions of the old valleys. But in descending on either side one encounters ever-deepening preglacial valleys heading in characteristic amphitheaters in which the evident erosion of the present streams has had comparatively little influence in molding the surface.

Postglacial Oxidation

The extent of the oxidation of postglacial deposits has been generally taken as one of the surest measures of the time that has elapsed since they were laid down. There is no question about the increase of this oxidation as we go southward to the glacial boundary, and also as in many places we penetrate older glacial deposits that have been overridden by later ones a considerable distance north of the extreme limit of the ice extension. North of the watershed in Ohio there is a pretty uniform blanket of yellow till from 10 to 15 feet in thickness overlying a less oxidized blue till of much greater average thickness. Moreover, between these strata there is quite likely to be a deposit of gravel, indicating the temporary influence of flowing water. Toward the southern part of the State the thickness of this blanket increases until when we pass the boundary of the so-called Wisconsin deposits the entire mass of till seems to be thoroughly oxidized.

But Prof. E. H. Williams again, in his extensive observations on the attenuated border of glacial deposits in Pennsylvania, has brought to light facts which have apparently escaped the notice of other observers, and which lead to entirely different conclusions from those which have ordinarily been made respecting the age of the so-called Illinoisan, Kansan, and pre-Kansan deposits. The facts are that, mingled with this highly oxidized material throughout the "attenuated border" in Pennsylvania, there are pebbles of the same character which are only slightly oxidized, indicating that the mass of oxidized material was already oxidized when it was picked up and deposited by the ice, and is therefore no criterion of the length of time which has elapsed since its deposition. But it is the comparatively unoxidized material mixed with it which indicates the time of the deposit. Furthermore, Mr. Williams observed

innumerable cases where water-worn Canadian pebbles had evidently been oxidized inwards until a core of unoxidized material remained in the middle, when afterwards they had been taken up by the ice and in the process of transportation glaciated on one side until the unoxidized core was almost or entirely exposed on the glaciated side, while the oxidized portion retained its original thickness on the other side. These pebbles therefore indicate that the oxidation had taken place mainly in pre-Glacial times, proving that it is no criterion touching the time of its transportation by the glacier.

Again, the amount of postglacial oxidation of the glaciated surfaces, even over the area covered by the Kansas invasion, is in many instances so small as to forbid the supposition of the enormous lapses of time which are currently made concerning the date of that invasion. In my original observations upon the glacial deposits in Saint Louis, Missouri, which are certainly as old as any, I found extensive limestone areas freshly uncovered near the Botanic Gardens which still retained glacial markings on their surface where not deeply eroded by chemical action. In the enormous lengths of time usually supposed to have elapsed since this glacial action the thin beds of limestone would have entirely disappeared.

Again, Professor Williams' observations upon the mammoth coal vein near Pottstown, Pennsylvania, where its surface had been glaciated in close proximity to the unglaciated area, disclosed the fact that, though the superincumbent soil was easily permeable to water and its eroding acids, the glaciated surface had not been eaten away to any appreciable extent, whereas a short distance beyond, in the unglaciated area, the coal was rotted to a depth of several feet.

I quote from a private communication, giving unpublished results of Professor Williams' observations on the attenuated border in Pennsylvania:

"The outcrop of Oriskany sandstone north of the Blue Ridge shows the coarse-grained variety cemented by calcite and carrying *Spirifer arenosa* and the cherty band.

"[But] the pebbles of the former can be traced through the moraine of Lewis and Wright and across the great valley of Pennsylvania; thence over the South Mountain, being carried from 250 above tide over the summit at 900 above tide and down the south slope to and half way across the Saucon Valley (average elevation, 400 above tide). These pebbles are mingled with local material, mostly angular. The local stuff is weathered and rotten; but *there is absolutely no difference in color, weathering, or degree of disintegration between the pebbles found on and south of South Mountain and those found in the moraine and even in the Lehigh at the foot of the outcrops.*

"*Slate.*—The outcrops of slate south of the moraine of Lewis and Wright are under a cover of gravels. Near Slatington workable slate is quarried immediately under these gravels, and there is no difference in appearance between them and the gravels of the terminal moraine.

"*Coal.*—The gravels at Morea, Pennsylvania, are neither oxidized nor rotten, nor in any manner capable of separation from the gravels of the Lehigh water level or of the moraine. They are abundant in sands, which are like the sands of the Pocono outcrops, or at Glen Summit, Pennsylvania, or above the coal outcrops north of the moraine of Lewis and Wright, and there is nothing to distinguish them either in color, degree of disintegration, or other characteristic dependent on age from outcrops to the north. They are 10 feet thick on an average. Immediately under them are the vertical outcrops of the mammoth bed. Weston Dodson and Company mined this bed and sent every particle of the same to market. Analysis of fixed carbon and ash in samples taken immediately under the gravel and 100 feet underground showed that there was not 2 per cent of difference between the samples and between samples of the same bed, which were flat and not in any manner influenced by surface water. Now, it is a well known fact that samples from the same bed and the same belt in the bed taken 10 feet apart may differ from 5 to 10 per cent in these things, and I have seen in the same mine a bed 11 feet thick of clean coal gradually diminish to a dirt bed 1 foot thick, and that within 1,000 feet. We can, therefore, conclude that the 2 per cent variation shows an agreement between the two samples at the surface and immediately under the gravel, and at depths as great as between any two samples of coal in any anthracite mine.

"On the other hand, 1 mile south of the limit of the 'border' and the mine next to it there is the usual 'peacock' coal in the outcrop, showing influence of weathering and the inclosing rock rotted soft for several feet from the surface, as is the usual occurrence, and this also occurs north of the 'border,' where the ice poured over a ridge and left the outcrops immediately below the crest untouched, as in the 'crag and tail' cases, which are infinite in number and identical.

"*Loss of calcite in glacial deposits.*—The Hydesville, Pennsylvania, overwash gravels of the moraine of Lewis and Wright are taken as of the latest age. These are cemented by calcite, and the shells in the red sandstone are generally dissolved to form the binding material, as is also the case in the gravels near Warren at both high and low levels, so that there is no difference in the induration from calcite cementation to be seen between the 'hard-pans,' as they are called, before and behind the moraine. The marine shells in the drumlins of Massachusetts have disappeared and their place is taken by sand concretions cemented by their calcite. These are behind the moraine of Lewis and Wright and so of the latest period. In fine there is evidence that generally the calcite in the glacial deposits, in the form of shells, has been leached away either before or since the deposit of the fragments in the drift. This is not always the case, and about Warren, Pennsylvania, cobbles have been found with portion of the shells undissolved in gravels, which can be traced continuously from the alleged 'rock-shelves' to the present levels.

"Now, from these evidences it seems that the times of the 'border' were very

recent; so recent that at the places indicated there can be no distinction made between the transported materials of the border and of the moraine.

"*The character of the original material of the glacial accumulations.*—We must agree that the ice could not attack the solid outcrops until the soil rotted in place had been removed. The depth of that soil varies according to material, slope, and climate. Agassiz reports soil over 100 feet in depth along the Amazon.

"Before the solid, rocky portion of the outcrops were reached there was pushed before the glacier this oxidized soil without distinguishing characteristic. I have advocated several times the study of the soil of the 'border' under the microscope, as our petrographic knowledge is so sure that it may be possible to detect and distinguish varieties in an apparent homogeneous body of oxidized soil.

"Next.—The glacial scrapings then were mingled with the rotten portions of the solid rock next the outcrops, and these were glaciated, as shown in the pebbles found at Warren among the gravels, where the river action was strong, and also in a cobble of gneiss found west of Irvineton on the top of the hill and several hundred feet above the river. Here the solid nucleus was within half an inch of one side and 3 inches from the opposite surface, showing weathering before rounding, and the rounding was from ice rather than water, as it was above stream action.

"The slate region of the Great Valley of Pennsylvania, from the Lehigh to the Schuylkill and utterly south of the Moraine, which was 30 miles to the north, was a good field for inspiring patience. In the first place the slate was so solid under the thin soil that post holes had to be cut into it for the fences, and the posts had to be wedged in with cobbles collected here and there from a region generally free from such things.

"In this region there was a fresh slate surface, coming sharp and solid under an oxidized deposit of soil, which was not slate soil. On this area there were at times masses of the rocks of the crest of the Blue Ridge moved a mile or more to the south and sometimes as large as a small house. At other times I have followed a section which went to the solid slate, and in the uniformly well rotted and fine soil there was not even a slate flake. Here was evidently the original preglacial soil. After a mile or so of search along a section I have found an Oriskany or Oneida pebble, and it was as fresh as pebbles usually are that are in oxidized soil, and that means a thin yellowing stain on the outside, but not extending inward more than a hair's breadth. Then I would come upon a sporadic deposit of gravelly soil.

"The influence of a rotted soil containing a large amount of iron peroxide is shown in the pebbles (Olenellus quartzite) of the basal conglomerate of the Triassic, just south of the South Mountain, at Hosensack, Pennsylvania. This conglomerate has thoroughly rotted, and its pebbles lie in the red and loose soil and very much resemble a glacial deposit; but the pebbles are as hard as if rolled today and with the steely-blue patina of magnetic oxide. Their section shows that the iron penetrated more or less deeply, and in every case there is no difficulty in picking them from a mixture of Olenellus pebbles from more northern localities.

"*Old glacial deposits.*—These must show a difference from fresh ones. The characteristics of a fresh deposit are that its oxidized character shall not vary

between the condition at the surface and at any depth if the deposit is the result of one and the same action. Even if there be a terminal moraine which has taken a million years to form, and the ice front has never moved from one spot for that time, and the lower portion be rotten while the top is fresh, if we suppose an advance of a mile, we will have whatever is carried onward mixed up in the carriage and deposited with a generally uniform appearance at top and bottom. We conclude, therefore, that when a deposit shows a similar state of oxidation at top and bottom it is not soil rotting in place, and if it shows no signs of stratification it is not sedimentary unless the conditions of sedimentation were identical during the period covered by the whole of the deposit. The presence of glaciated stones will, however, settle the matter.

"On the other hand, if a glacial deposit, which at the beginning showed the above characteristic of uniformity, lies for ages, say one thousand years, under the influence of weather, frost, rain, etcetera, we can readily see that the surface must begin to show a weathering distinct from that which was shown at all depths by the weathered portion of the original deposit, and this weathering in place will extend to varying depths according to the openness and porosity of the mass; but in every case there never will be a uniformity of weathering between the top and bottom layers of the mass.

"We have, therefore, an infallible criterion for gauging the age of a glacial deposit. There will be three conditions:

"First. There will be a deposit which has been formed by the long continued action of a glacier forming a moraine at a given line of advance. Here the lower part of the deposit is the most oxidized and the fresh and recent material is on the top.

"Second. There has been the formation of a terminal moraine by an advance followed by a continuous retreat. Here the criteria will be of two kinds:

"*a.* It is an old moraine and the surface is more oxidized than the base, or

"*b.*, It is a comparatively recent moraine and there is a uniformity of oxidation from top to bottom.

"From the latter we see that whether the contents be fresh or completely rotten, the recency is shown by the uniformity of oxidization throughout, so that there may be a recent moraine of entirely rotten and oxidized material if the material was taken from a rotten surface, as well as a recent moraine of perfectly fresh material taken from a well glaciated surface. Again, if we find at all levels freshly rolled material mixed with perfectly rotted and oxidized soil the formation is recent.

"We can deduce the general rule:

"Absolute uniformity in characteristics of a deposit of glaciated material at all levels on a vertical section shows recency of formation, and it is immaterial whether the deposit consist of entirely fresh, entirely oxidized, or mixed fresh and oxidized material."

These various observations certainly nullify the evidence usually adduced to prove an enormous lapse of time since the culmination of the Glacial period, and support the earlier conclusions of Dana, Hitchcock, Upham, and others, that the upper and lower till are quite distinct in

their methods of accumulation. The upper till is for the most part material which was held in the upper strata of the ice, and which gradually accumulated in thickness toward the south as the ice melted and deposited its earthy material upon the lower surfaces which were exposed. During this long exposure this material of the upper till underwent a great amount of oxidation, while the lower till was protected from oxidizing agencies. Moreover, the material which had been oxidized in pre-Glacial time was that which was first picked up by the continental glacier and incorporated in its mass and carried onward far toward the southern limit. When the movement had proceeded as far as to the time of the Wisconsin episode, the surface rocks of Canada had been denuded of this oxidized preglacial material, which readily accounts for the comparatively small oxidation of the Wisconsin till.

One other point should be kept in mind. As the surface of the ice moved faster than the bottom, much of the material which was carried high up in the glacier would be thrown forward upon the margin and become mingled with the material which was underneath the glacier; so, in periods of advance, after a time of recession this would become a part of the ground moraine and be overridden by the ice, thus furnishing a lower stratum of highly oxidized material covered, as the ice advanced, by a later stratum of less oxidized material. Failure to keep these considerations in mind will lead to erroneous inferences concerning the age of deposits of highly oxidized material lying underneath deposits of less oxidized material, for on a little thought it is evident that the two deposits need not be far separated in age, for the earlier oxidized material is constantly being thrown forward, to be overrun by later movements of the ice in close succession. Every pause in the movement of the front, or temporary recession, would be marked by an accumulation of highly oxidized material, to be covered by deposits of less oxidized material that were continually advancing. The complete oxidation of such a basal deposit would be no evidence of great age.

Conclusion

While this evidence does not give us any very definite conclusions as to the age of the drift upon the attenuated border of the glaciated region, it is sufficient to throw doubt on the extreme figures made to represent the length of inter-Glacial and post-Glacial time. The physical conditions of the Glacial period were so abnormal that we are not permitted to apply to that period measures which are drawn from present earth movements and rates of erosion and deposition. It is pretty certain that

the departure of the Wisconsin ice-sheet took place not much more than 10,000 years ago, and that the date of the Kansan deposits should be reckoned in tens of thousands of years rather than in hundreds of thousands of years.

Discussion

Mr. Leverett called attention to great erosion in the upper Alleghany region which took place between the deposition of the old drift and of the young or Wisconsin drift, and which should be considered in estimating the relative ages of these drifts. Valleys which were filled with the older drift to a height of 200 or more feet above the present streams were largely reexcavated prior to the later or Wisconsin ice invasion. Evidence that they were filled to this height is found in level-topped remnants of the old valley-filling preserved in recesses on the sides of the valleys. Evidence that much reexcavation had occurred is found in the fact that moraines of the later drift pass down into the low valley bottoms instead of terminating up on the surface of the earlier drift filling. Moraine-headed terraces that represent the glacial drainage from the later ice-sheet start at levels only about 50 feet above the present stream. From this it appears that erosion since the last glaciation is but a small fraction of that between the deposition of the old drift and of the young or Wisconsin drift. The aged aspect of the old drift may therefore be something acquired since its deposition. The incorporation of preglacially weathered material, while no doubt a fact, may not have been of sufficient amount to be a dominant feature of the earlier deposit.

Prof. H. L. Fairchild said: The question of the length of post-Glacial time is always interesting, and while we as yet have no yardstick of geologic duration, the maps yet before the audience in illustration of paper 31 will give us a suggestion. How long has Lake Ontario existed? (The replies ranged from 15,000 to 25,000 years.) Let us take 10,000 years for the life of Ontario. Then preceding that was the marine submergence, with the slow lifting of the land and production of the remarkable series of heavy, close-set bars on the marine shore (at one place 42 bars in a distance of 1¼ miles and a vertical fall of 165 feet), which may be taken as at least another 10,000 years; then the long-lived Lake Vermont, New York, with its expansive deltas and good beaches; then the briefer Lake Emmons; then the Lake Iroquois. All this in the Saint Lawrence Valley, which represents only the later part of the post-Glacial time, since the terminal moraine was deserted, and which must be at least 30,000 or 40,000 or 50,000 years, and may be twice that.

Dr. J. W. Spencer said: Professor Wright's determinations of the rapid erosion by weathering, seen on the sides of the Niagara Gorge, is based upon artificial conditions. The railway cut has steepened the natural slope covered with talus; consequently the rate of lateral erosion now found here is excessive. Furthermore, the lower levels of the gorge wall became exposed only after the sinking of the waters to and below that of the Iroquois beach, and, on account of the later exposure of the slopes and the subsequent overdeepening of the gorge, when all the lake waters were turned into Niagara, the lower slopes were excessively steep, and, when exposed to weathering, such would favor very rapid removal of the debris and shales.

Professor Wright's reply: The movements of land level during the Glacial period were abnormal and can not be judged by present movements. The relief furnished by the removal of the ice-sheet led to a rapid reelevation of the land, so that the 1,000 feet may easily have been accomplished in 5,000 years.

The Conewango was never filled with gravel to the height of 300 feet. The deposit at East Warren is a dump in the lea of a rocky projection, while on the west the glacial torrent scoured out the channel.

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PLATEAU OF BRITISH EAST AFRICA[1]

BY GEORGE LUCIUS COLLIE

(Presented before the Society December 30, 1911)

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INTRODUCTORY

The observations embodied in this paper were made along the route of the Uganda Railway during the months of July and August, 1910.

[1] Manuscript received by the Secretary of the Society January 29, 1912.

Somewhat extended journeys on foot were made in each of the physiographic provinces of the area. No long trips were taken away from the railroad, however, nor were they possible except by organizing a safari, a method of travel beyond the author's means. Longer trips into more remote regions would have brought out many added details and doubtless some modification of statement, but it is not believed that they would have changed materially the conclusions of this paper.

The area to be discussed in the following pages is a portion of the great plateau of central Africa. A brief summary of the conditions obtaining in this relatively unknown region should be given at the outset, that there may be a clear understanding of the plateau and of the problems connected with its development.

The foundation of the whole area under consideration is an ancient, gnarled, and foliated gneiss which forms the surface rock over wide stretches of the central portions of the plateau. The region has been peneplained and exhibits two cycles of erosion. The surface of the plateau is strongly graded and slopes to the eastward. The average rise from the Indian Ocean to the summit of the plateau west of the Rift Valley is about 20 feet to the mile. The eastern portion of the region has been depressed below sealevel, and upon it a series of clastics has been deposited, these rocks being mainly Mesozoic in age. The coast has passed through a number of minor oscillations since that time. The western part of the plateau has been covered by floods of lava, which have come from the present site of the Rift Valley, the earliest of these lavas being probably of early Tertiary age.

Either during or following the extrusion of the lavas there occurred the trough faulting which resulted in the formation of the great graben known as the Rift Valley, the most remarkable feature of its type in the world. The Nile basin has been excavated out of the plateau, and erosion is still attacking the western face and causing a marked eastward retreat, which will ultimately result in the obliteration of the rift and the addition of its present area to the drainage system of the Nile.

In this paper it is proposed to describe the plateau and to consider its problems under three heads, as follows:

A. A description of the country as an example of the relation of geological structure to topography.

B. A discussion of the possibility of peneplanation at high altitude without any stage of high relief. This question at present must have a theoretical aspect, yet it deserves careful study and thought. The conditions on the high plateau of Africa indicate the possibility of reducing the level of a country from a high altitude to a low without any stage of marked relief.

FIGURE 1.—COASTAL PLAIN AT MOMBASA

FIGURE 2.—TOPOGRAPHY OF THE FOOT PLATEAU, NEAR THE COAST

THE COAST REGION

C. The Rift Valley is described as an example of an unusual and peculiar physiographic type.

Physiographic Provinces and their Relation to geological Structure

Five provinces may be recognized, extending in long, comparatively narrow belts in a northerly-southerly direction. They are as follows: 1. The coastal plain. 2. The foot plateau, an uplifted Mesozoic coastal plain. 3. The gneiss province. 4. The lava province. 5. The Rift Valley. The rift lies wholly within the lava province, but it is such a pronounced feature that it deserves treatment by itself and under a separate head.

The coastal Plain

THE SHORELINE

The coastal plain is a narrow belt of recent coral rock, possibly of Pleistocene age. The plain averages a width of 3 or 4 miles and is about 30 feet above mean tide, on the average. It presents a cliff frontage to the sea generally and the cliffs have been eroded into fantastic forms by the ocean. Wherever there are coves or in the neighborhood of streams beaches occur. Generally they are small pocket types, but in some instances they are extensive and front the shoreline continuously for miles. Below the base of the cliffs, partly exposed at low tide, there is frequently a wave-cut rock terrace of varying width.

On the whole, the coast presents a smooth outline; the irregularities are due mainly to the coral reefs and to the drowning of the stream deboucheres. The coast is young and wave erosion has not made serious inroads upon it as yet. Outside the present shoreline, fringing and barrier reefs are forming in great numbers. In general they lie parallel to the coast, and some of them are so close to the surface that sand is accumulating upon them; this is true even of barrier reefs several miles from land. A slight elevation would extend the shoreline seaward for some miles. The east coast of Africa is one of the great coral belts of the world. From Somaliland—with few interruptions, as off the mouth of the Zambesi River—to the neighborhood of Delagoa Bay, a distance of 2,000 miles or more, the prevailing coast formation is coral.

STRUCTURE AND CHARACTER

The coastal plain is largely one of marine denudation, but in many localities bordering the lagoons there occur beds of more or less consolidated derivative coralline sands, succeeded by beds of loose quartzose sand and gravel, the latter derived probably from the gneiss formation

of the interior. All of the formations, whether resulting from degradation or aggradation, combine to form the low-lying, flat, featureless coast plain, ranging from 2 to 10 miles in width. The surface of the plain is covered by a thin residual soil on which a luxurious tropical forest subsists. The coral rock which underlies a greater portion of the plain is usually quite porous and brecciated. Rainfall sinks into it rapidly and seeps away to the sea; there are few streams as a result.

In some cases small rivers originating in the interior cross the plain; they generally have short courses and few tributaries, and have had but little effect upon the topography. Their lower courses are drowned, causing irregular and widely expanded estuaries, such as form Mombasa and Kilindini harbors, the latter one of the great and splendid harbors of the world.

The sand and gravel beds of the coast plain are easily eroded, and are well dissected by ravines a few hundred yards in length. The lower courses of these ravines are depressed and become the seat of delta-like deposits, the tidal portion of which is covered with mangroves, while the

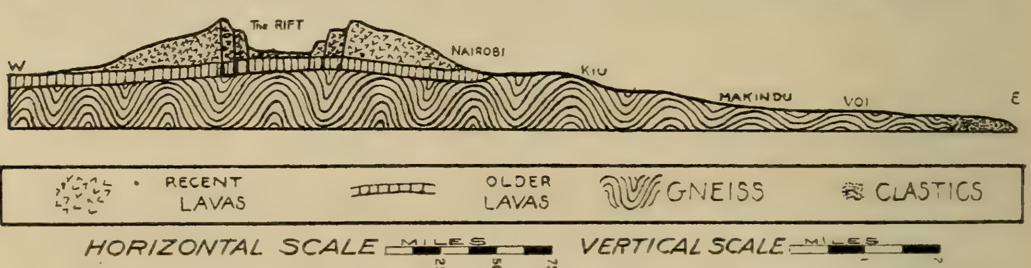

FIGURE 1.—*Section of the Plateau from the Indian Ocean to Victoria Nyanza*

upper part, above the tide, is used by the natives for their banana shambas. The ravine floors pass beneath the surface of the water. The 10-fathom contour in the lagoons is frequently notched opposite some of the larger ravines, suggesting that they have a submarine extension. It seems probable that the land has stood at least 60 feet higher than at present within recent time. If the conjecture of Muff,[2] Gregory,[3] and others is correct that the coralline sands are Pleistocene, then the uplift must have taken place late in that period or subsequently. The present depression, which is the last phase in the diastrophic history of the coast, must be very recent, if not now in progress.

THE FOOT PLATEAU—ITS CHARACTER AND STRUCTURE

Gregory uses the term foot plateau for the narrow and relatively steep front of the plateau, which faces the Indian Ocean. He limits it to that

[2] H. B. Muff: Col. Rep. No. 45. London, 1908.

[3] J. W. Gregory: The Great Rift Valley. London, J. Murray, 1896.

portion underlain by shales; but, as there is a large series of sedimentaries underlying the shales, there seems to be no reason for discrimination between the shales and the underlying clastics from a physiographic standpoint. It seems best to consider all that portion of the plateau covered by sedimentaries as one province, under the title of foot plateau.

The sedimentary rocks of the coast, according to Muff, are as follows, in the order of their occurrence:

Raised coral reefs and Pleistocene sands (Kilindini sands).

Unconformity

Changamwe shales, limestone at the base.

Mazeras sandstones, pisolitic limestone near the top.

Mariakani sandstone.

Maji ya Chumvi beds.

Taru grits.

Unconformity

Gneiss.

The clastic rocks have been laid down conformably one upon the other, and have been uplifted, tilted, beveled as one common unit. Their age ranges from the Carboniferous (?) to the Jurassic. The shales, which are the youngest of the series, it seems quite certain from fossil evidence, are late Jurassic. The foot plateau has been canted over, depressed beneath the sea, and uplifted, and it is simply a raised coastal plain of Mesozoic age.

The plateau rises with some abruptness from the water level to a height of 200 feet. This slope, as already indicated, is an old sea cliff; at its base is a wave-eroded platform of varying width cut in the coral rock. The shales which lie exposed on this plateau front are soft and easily weathered, thin bedded and thoroughly jointed, and are easily acted upon by erosive agents. This portion of the area is, as a result, maturely dissected and presents a series of round, knobby hills with steep slopes, separated by numerous ravines.

The work of erosion is performed quite largely by intermittent streams, which have pushed their way headward into the interior from the coast plain for a distance of 20 miles or more. The larger ravines lie 100 feet below the inter-ravine spaces; numerous side ravines have been developed, the whole forming a minute dendritic pattern.

To the west of the shales are the older and coarser clastics; these grits and sandstones are harder and more compact than the shales and they have a different topography. The transition from the shales to the sandstones is announced topographically by a relatively steep escarpment, 150 feet high on the average, known as the Ndunguni Hills. Differential

erosion has removed the softer shales and left the harder sandstone outstanding as a prominent ridge, a notable object in the landscape as one approaches the African coast.

In this sandstone and grit belt the country becomes a flat plain of low relief, in marked contrast to the shale belt. The region has every appearance of peneplanation. It has very shallow valleys, as a rule, and they are occupied by intermittent streams. The valleys are wide, with long, sloping sides, while at the bottom there is a stream channel made during the previous rainy season. This channel is usually a steep walled ditch made in alluvium, and only a few feet in width or depth. The largest permanent stream observed on the foot plateau is the Mwachi, with well-developed entrenched meanders 250 feet below the general level of the country. The entrenching represents a period of uplift probably to be correlated with that in which the basins of the coast lagoons were eroded during the later Pleistocene. The entrenching is marked only near the coast; a few miles inland it has disappeared; the diastrophic movements which caused it must have been relatively local. On the peneplained portion of the foot plateau the few streams which occur are almost invariably consequent upon the strong seaward slope of the plateau. A few short subsequent streams have been developed along the strike of the eastward-dipping rocks, but these as yet are of small moment. All of these streams have the characteristic wide valley with its gently sloping sides. The valley sides are rarely dissected to any extent; indeed, they are hardly to be characterized as erosion slopes in the common acceptance of that term. They are soil-creep slopes or sheet-flood erosion slopes; that is, slopes degraded by planation processes rather than by concentrated drainage.

Much of this portion of the foot plateau is covered by a thick, almost impenetrable thorny scrub; it is a desolate, uninhabited region, forsaken alike by man and beast.

The Gneiss Province

Character and Structure

Throughout the middle portion of East Africa, gneiss is the country rock. It was the original massif of the continent; the total width of the belt is 200 miles. It is a peneplained region, with numerous residuals of gneiss. In local areas there are lava flows which proceed from fissures or from mound-like volcanic cones. Generally speaking, this region, like so much of central Africa, is exceedingly monotonous, and one is overwhelmed not so much by the wide expanse of rolling plains as by their sameness mile after mile. African topography is not, as a rule, a suc-

cession of pleasing and attractive scenery; it consists of great areas without much contrast—vast regions of one physiographic type that pall on the traveler as he journeys over them.

The gneiss is coarse-grained, extremely foliated, and exhibits rather remarkable uniformity of structure wherever it is found; the foliation trends quite uniformly north-northwest south-southeast. The foliation and the coarse character of the rock indicate that the original topography was mountainous, but the mountains have been removed, for the earliest of the existing surfaces is a distinct peneplain. This early or first cycle surface is found on the Kapiti plains at an elevation of 5,300 feet. To the eastward the second cycle is well advanced and its surface lies 2,000 or 2,500 feet below the level of the first cycle surface. The original plateau represented by this higher surface apparently reached its culmination in the region of the present Rift Valley. It had seemingly gentle slopes eastward and steeper ones to the west. These slopes are inferred from the fact that the vast lava extrusions in the neighborhood have flowed both eastward and westward from the Rift region.

The original height of the plateau must have been from 8,000 to 10,000 feet, judging from altitudes now remaining as remnants on the Kinakop and Mau portions of the plateau.

VALLEYS AND DIVIDES

On the eastern border of the gneiss belt the physiography is not materially different from the region immediately preceding it. It is at the outset a level, monotonous region of small relief, with broad, shallow, flat-floored valleys and ravines.

The country is all slopes, and every drop of rain that falls has some long debris-laden incline at hand down which it may travel, but there are no sharply incised stream valleys. The existing valley floors and sides are covered with thick alluvial soil, for the most part, and aggradation is effective as a topography-maker.

MONADNOCKS

Beginning in the region of Maungu and extending to Kiu, monadnocks are a feature of the physiography; they are typically shown in the region of Voi. In general the gneiss residuals are ridges which lie parallel to the foliation of the gneiss. Some of the monadnocks have steep and precipitate sides; in some cases they are evidently fault-scarps; in other instances the slopes are gentle, consisting of talus slopes with slightly concave surfaces which lead away from the residuals to the general level

of the country. The monadnocks of high altitude are deeply eroded; their sides are gashed by ravines which reach from summit to base. The greater precipitation at the summits is the reason for this condition.

In the Voi-Makindu region erosion has gone on to such an extent that the monadnocks form barely 10 per cent of the total area. In the region of Kiu they are much more numerous and closer together, and here fully one-half of the region remains comparatively unattacked.

THE RELIEF

At the eastern border the gneiss plateau is 1,100 feet above the sea; near Kapiti plains, where the lava flows begin to cover the gneiss, the elevation is 5,300 feet; the average rise is 21 feet to the mile. For the first 50 miles, until Voi is reached, the average rise is only about 15 feet to the mile. From Voi to Tsavo there is a drop of 300 feet, Tsavo being located in a depression probably of tectonic origin. From Tsavo to Makindu the rise is 24 feet to the mile; from Makindu to Kiu, the latter in the more uneroded portion, the average gradient is 30 feet; from Kiu to Machakos Road the average rise is 100 feet to the mile.

As has been indicated, the gradient of the plateau is greater than ought to be expected from normal erosive processes. It suggests again that tectonic movements have helped to make this relatively large gradient. In general the gneiss plateau has a thick soil, alluvial in the shallow valleys and residual on the divides. The country is open and parklike; trees and bushes of semi-arid types abound in most localities. Recent lava flows sometimes cover the gneiss locally; they smooth off even the faint relief of the gneiss, as about Simba, where thin flows spread out from small volcanoes and cover the country to quite an extent. On the other hand, near Kenani the Ndunga and Yatta flows of volcanic origin enhance the relief of the region. These hills have a sharp rectangular outline, which stands out in marked contrast to the flowing outlines of the gneiss hills. The Ndunga hills form a remarkable mesa 170 miles long and but 4 miles wide; the lava which formed the flow came from a fissure of the same length, according to those who have examined the region.

The Lava Province

EXTENT

This great region extends from the Kapiti plains to Victoria Nyanza, a width, measured directly, of 180 miles. The lava belt is of unknown length, but extends across British East Africa far north into Abyssinia

and south into German East Africa. The lava flows are probably co-extensive with the Rift Valley itself, and the great lava area formed by them is likely to prove on investigation to be the most extensive one on the globe. It is estimated that lava covers 150,000 square miles in British East Africa alone. Of this area, the lava province on either side of the Rift Valley covers one-half.

CHARACTER AND STRUCTURE

The lava province is divided into an eastern and western portion by the Rift Valley, which crosses it from north to south. The eastern or Kikuyu field is about 60 miles in width, and includes all that portion of the lava area between the gneiss area and the Rift. The lavas belong to two distinct periods; the earlier lavas are generally the more basic in composition, and they are also more deeply weathered and leached than the later lavas. The younger lavas are acid types allied to rhyolites and phonolites; generally they are quite fresh in appearance and show relatively little weathering. The older lava flowed the farther from its source and extends beyond the range of the later extrusions. On the eastern border of the Kikuyu field the lavas are the more ancient type; here they form thin beds, which scarcely mask the old peneplained gneiss surface. The Kapiti and Athi plains, with their very flat, prairie-like surfaces, are formed by these old sheets. Farther west, in the vicinity of Nairobi, great volumes of more recent lavas have swept down from the Rift region, effectually covering the previous deposits and introducing another and bolder type of topography, with strong slopes and deep, ravine-like river valleys.

The western or Nandi region has a width of about 60 miles on the average, and extends from the west side of the Rift to the shores of Victoria Nyanza. Unconsolidated pyroclastic material is abundant over the surface, but the lavas are much the same type as in the Kikuyu field, and occur as there in two distinct periods. Some of the earlier flows reach the shore of the great lake, while the more recent flows fall short by several miles, presenting steep, terrace-like fronts to the lake. Both types of lava flow around and partially cover old granitic ridges and peaks.

DRAINAGE SYSTEMS AND VALLEYS

On the older lava fields of the Kikuyu region there are a few inconsequent streams which come down from the west from the higher portions of the plateau. The valleys are wide and shallow, the interstream spaces are broad, and there is little relief. On the divides the soil is thin and

the underlying rocks are frequently exposed; everywhere residual boulders of lava cover the plains.

The newer lavas have been poured forth in such abundance that they have destroyed the previous drainage and imposed new conditions. Steep slopes have been made, extending from the Rift out upon the Athi plains to the east. The average gradient of the old lava slopes is three feet to the mile, while that of the new lavas is 75 feet.

The introduction of these new slopes served to bring in a new drainage scheme. The streams flow down slopes in courses of remarkable parallelism, and they are all true consequent streams—consequent upon the slopes determined by the flow of the lava. In their upper courses the streams are actively eroding; they flow in V-shaped valleys that reach depths of 100 feet or more. The sides of the valleys, though steep, rarely show outcrops; there is usually much fine soil, partly residual, partly volcanic dust. Numerous ravines are developed on the valley slopes, and these reach back into the flat, relatively narrow interstream spaces. The country is well dissected, though it has not yet reached maturity. The streams flow across a succession of hard and soft lava beds. In the softer rocks, wide open, amphitheater-like valleys are formed. The streams tend to be ponded by waste, with the result that small lakes and marshy areas abound. In the harder beds the valleys are narrow, georgelike, and ungraded. Near the Rift the valleys become narrower and deeper, and there is a great development of ravines, which are forcing their way back into the Rift itself, and which some day they are bound to penetrate and to drain.

On the Nandi side the drainage conditions are somewhat different. The descent from the Rift to Victoria Nyanza is about 4,350 feet—an average of over 70 feet to the mile. The rainfall is about 60 inches annually. Under these conditions erosion is a tremendous factor.

The comparatively narrow divide between the Rift and the Victoria basin is being attacked with vigor, especially from the west. On the western slope at the very outset there are deep, intricate ravines uniting to form permanent streams. Dissection has become mature, though numerous buttelike residuals remain scattered over the face of the country. There is everywhere in this area a tumult of divides and deep valleys, spurs, ridges, crests, amphitheaters, and pinnacles. The V-shaped valleys are frequently 500 feet in depth. About half way to the lake, in the region about Fort Ternan, the country is more maturely dissected and fewer residuals occur. The valleys are wider and more shallow; this is increasingly the case as the lake is approached. Finally the valley

FIGURE 1.—MONADNOCK, NEAR VOI

FIGURE 2.—DETAIL OF SURFACE ON THE HIGH PLATEAU: MAKINDU

THE PLATEAU REGION

walls disappear and the rivers flow out on great alluvial fans and make their way over them into the lake.

Peneplanation of the Plateau

CHARACTER OF SURFACE AND ITS ELEVATION

The most notable feature of the plateau is its peneplained condition; the surface is beveled in a marked way and without reference to foliation or other rock structures. The plateau surface has a strong gradient developed by the peneplaining activities; this gradient slopes toward the ocean as if the sea had in some way controlled its development. The gradient, while averaging 18 to 20 feet to the mile, is by no means uniform, but varies in such a way as to suggest that there have been a series of tectonic basins or platforms connected with each other by slopes or scarps. It may be that the plateau was broken up into a number of great fault-blocks at one stage of its history. If so, the scarps and other irregularities have been smoothed down or removed by erosion and the whole surface graded to the fairly uniform slope that now exists.

Much of the plateau lies at an elevation of several thousand feet above sealevel. Under normal conditions, at such altitudes there would be marked relief developed, as, for example, in the case of stream valleys. The plateau, however, lacks these elements of relief; indeed, over much of its more arid parts deep valleys are conspicuous by their absence.

It seems probable that the plateau is being peneplained at high altitudes, without reference to sealevel or without the aid of stream erosion, at least in any large measure. As this method of peneplanation differs from the normal method, it is necessary to consider the factors entering into it. Of the various factors, the principal one is the climatic one. Other minor ones are the depth of the water table, texture and structure of the rocks, absence of high mountain ranges to furnish constant supplies of water for through trunk streams.

CLIMATIC FACTOR

The climate apparently has a more important bearing on the question of peneplanation than any other factor. From the climatic standpoint it is possible to divide the country into zones parallel to the coast. The rainfall at the coast and for 30 or 40 miles back is about 32 inches annually, though this amount fluctuates greatly. Then follows a belt about 275 miles wide in which rain is scanty. In this belt, however, the higher elevations, such as the summits of the monadnocks and the more elevated

portions of the plateau to the west, receive more rain than the plains below.

To the west of this arid belt, toward the Rift on the high plateau, the rainfall is about 42 inches per year. The Rift forms a narrow but arid belt, depressed below the plateau from 1,300 to 2,000 feet.

Here the rainfall is scanty, and this belt is, on the whole, the driest of the whole region. Passing over the divide that separates the Rift from the basin of Victoria Nyanza, an annual precipitation of 60 inches is found. There are, generally speaking, two rainy seasons; the greater rains fall from March to June, the lesser rains in November and December. The two wet seasons are thus separated by months of dry weather, during which the soil becomes parched, vegetation dries up, and arid conditions prevail. Thus the climatic conditions are such that there is a broad semi-arid belt, flanked on the east and west by narrower belts of rainfall. The east and west sides of the plateau, as a result, are seats of erosion, while the middle portion is a region of aggradation, on the whole. When the seasonal rainfall has ceased, the ground water near the surface is rapidly evaporated in the dry, hot climate which succeeds.

OTHER FACTORS

The water table lies at a great depth over much of the plateau in all probability. In a few instances, where wells have been drilled, it is found at a depth of 600 or 700 feet.

The rocks of the plateau in general contain a great many structural planes. Many of the rocks are porous and coarse-grained, and these conditions naturally facilitate the withdrawal of water to a depth.

There are no ranges of high mountains on the plateau which might furnish snowfields and glaciers for the constant supply of water through the dry seasons. One or two of the large volcanoes on the plateau—Kenia, for instance—are of such great height and size that they are able to maintain living rivers throughout the year—rivers which have volume enough to reach the sea. The Tana River flows from the Kenia region and reaches the ocean, but its course lies far outside the area described in this paper, and this exceptional stream can have little bearing upon the development of the plateau as a whole. The absence of mountain ranges precludes the existence of trunk streams, and hence it is that in this portion of Africa little of the interior drainage is able to make its way to the sea, or it does so only in an intermittent fashion, because it has no backing.

The various factors mentioned above all combine to form a type of peneplanation in which stages of great relief are lacking, because stream

work and corrasion are minor factors, the leveling work being performed by other agencies than streams.

METHOD OF PENEPLANATION

Putting the work of these factors together as they seem to operate, the method of peneplanation appears to be as follows: During the two rainy seasons of the year there are short, sharp showers, which fall on a deep soil from which moisture has been almost wholly removed by evaporation during the previous dry season. A part of the precipitation is readily taken into the ground and sinks down to join the deep water table. Intake of water is relatively large, for the underlying formations are not at all water-logged, and they can store all the water offered to them.

The run-off is depleted by this large withdrawal of ground water—so much so that it becomes speedily clogged by the great amount of dry, fine dust which has accumulated in the previous months of arid weather. There can be little concentration of run-off under these circumstances; it tends rather to move off down the slopes in sheetflood manner. The sides of the shallow valleys are very smooth, and their condition indicates that sheetflood work is important in developing them. As these overloaded sheets of water reach the valley bottom they form streams clogged with waste and incapable of doing much corrasion. The tendency is to aggrade rather than to corrade, and the valleys are deepened but slowly. Corrasion barely keeps pace with the general degradation of the country; at least it does not keep much ahead of it, and the deepening of the valleys does not gain materially on the general lowering of the region. Under such circumstances there will be little relief developed and peneplanation will go on without it.

During the dry season deflation becomes something of a factor, for the climate is truly arid for the time being. The seasonal winds are rather light and fluctuating, and are not very important in removing dust. On the other hand, there are numerous small local whirlwinds, which take place in the middle of the day over much of the plateau area, and they raise great quantities of dust high in air and bear it away to other localities. This deflation, together with the sheetflood erosion and possibly soil creep to some extent, are the agencies chiefly concerned in general degradation and in offsetting the feeble work of corrasion. Some corrasion takes place each year, and notably in the exceptional years when there is large general rainfall over the whole plateau; yet, as has been stated, it is never great enough to develop deep valleys nor to gain much over the general lowering of the surface.

In spite of different rock formations and of differing climatic conditions, the whole plateau is quite uniformly graded from ocean to summit near Victoria Nyanza. It is difficult to explain this rather uniform gradation in a satisfactory way, for it looks as if some one factor controlled the whole peneplanation, and that factor was the ocean. It is not easy to understand how the ocean, as baselevel, could control peneplanation on the high plateau, where arid conditions prevail, where deflation is important, and other factors are operative which are not controlled primarily by the sea.

The best explanation to be given is as follows: The ocean as a baselevel does control the outer belt of the plateau in proximity to it. This belt in turn does exercise some influence on the semi-arid belt which adjoins it to the west. The gradation of the outer belt is wholly carried on by normal erosion, and the amount of this gradation determines how much material may be carried out from the semi-arid belt at any given time and especially in those infrequent years when streams are able to leave the dry region and reach the sea because of heavy rainfall in the interior. There is always the possibility that material may be carried seaward from the interior. The amount that is to be carried in the favorable years will depend quite largely on the grades that exist on the outer humid belt down which the detritus from the semi-arid region must pass. In this way the outer humid belt has some control over the development of the wide, semi-arid belt of the interior. In turn the semi-arid belt controls the rate and kind of degradation on the wet belt of the high plateau to the west. There is abundant precipitation on this high plateau, and it is being degraded by the numerous streams which cross it.

These streams flow out on the dry belt of the plateau, where they wither and deposit their load as a result. A grade is consequently developed between the wet belt and the dry belt, a grade that can not be changed materially except through the cooperation of the semi-arid part of the plateau. In other words, the wet belt of the high plateau can not be degraded any faster than the semi-arid belt permits. There tends thus to be adjustment between all parts of the plateau in spite of climatic and other differences.

In the semi-arid belt there are numerous residuals, chiefly of gneiss. Rainfall is fairly constant and abundant on the summits of the higher monadnocks, and they are being lowered by normal erosion down to the level where the arid conditions set in. When the normal erosion ceases or is largely checked, then the residuals are lowered no faster than the general region, and they thus tend to be preserved indefinitely.

The second or lower cycle of erosion on the plateau is being developed

chiefly by deflation and sheetflood work. The first cycle, represented by the higher portions of the plateau and the summits of the higher monadnocks, is being developed by normal methods of erosion. All of the debris carried from the first cycle surfaces must finally be deposited on the second cycle surfaces below; hence degradation of the first cycle can not go on more rapidly than conditions on the second cycle surface will permit. If the second cycle surface is being rapidly degraded by the agencies operating there, then opportunity is furnished for the carriage of more debris from the first cycle surface and it is swept down readily, and degradation is thus accelerated on the first cycle surface in turn. The reverse is true if degradation is inactive on the second cycle floor.

The present topography of the semi-arid belt indicates forcefully that peneplanation takes place at high altitudes without the development of great relief. This type of peneplanation has been called an arid type, but the conditions in East Africa show that it may take place where rainfall is fairly abundant, provided it comes in widely separated seasons. Aridity is perhaps the great factor, but the conception of aridity must be broadened to include not only conditions where rainfall is scanty, but also those where it comes seasonally; and, under the latter case, where it falls in short showers with sufficient intervals to permit the soil to dry out between showers. Aridity the year around and aridity for a part of the year each will produce this type of peneplanation. It is not solely a question of the amount of rainfall, but of its distribution as well, and especially is it a question of its concentration within the limits of a few weeks. Peneplanation of the type here discussed will go on in any region, just as it apparently is doing in East Africa, provided there is a margin of arid conditions over humid conditions year in and year out. This type of peneplain should be looked for, then, not only in arid regions, but also in any region where there are short seasonal rains alternating with more extended dry seasons.

The method of peneplanation in East Africa calls attention afresh to the dangers attending current interpretations of this phenomenon. For instance, suppose that the climate of East Africa were to change in such a way that rainfall became abundant: the present intermittent streams would become permanent, the present wide, shallow valleys would be deepened greatly, and there would be a system of deep, youthful valleys developed in a peneplained upland. Generally speaking, current opinion would interpret this condition as resulting from a reduction of the region to baselevel, then a subsequent uplift, which rejuvenated the streams and developed a new cycle in the older one. It is evident that the whole phenomena could be brought about simply by a relatively small change

in the quantity and distribution of rainfall, without calling in the agency of diastrophism whatever. The writer has explained the peneplain in the driftless area of Wisconsin as due to the baseleveling of the region, possibly in the Cretaceous, followed by a subsequent uplift, which permitted the streams to renew their youth and to develop a second and well matured cycle within the old one. After his experience in Africa the author feels that possibly this former opinion is subject to revision, for the present conditions in Wisconsin may well have arisen simply through climatic changes.

The Rift Valley

POSITION AND EXTENT

If the supposition of Suess is correct, the Rift Valley extends from 15 degrees south to the neighborhood of Antioch, Syria, 35 degrees north latitude, a distance of nearly 3,500 miles. At its southern extremity, almost at the outset of its course, the valley forks; one portion proceeds to the northwest, while the other and main portion trends northward; it is a small part of the main valley that is here described. In this particular region the width of the valley from crest to crest is on the average about 70 miles, and that of the floor is about 40 miles.

The depth of the valley varies greatly, also, for the bottom rises and falls; there is a succession of basins separated by divides. Fault-block succeeds fault-block, and, in addition, the lava accumulations on the floor vary greatly in thickness. The depth of the valley ranges from 2,000 feet to 1,200 feet. In this region the valley lies on the very western edge of the high plateau, just before the descent into the Victoria basin begins, and the divide between the two is relatively very narrow. The western escarpment of the Rift is generally more elevated than the eastern one and it is the real summit of the whole plateau.

ORIGIN

The Rift Valley must be regarded as a vast graben or tectonic trough; the undulations of the floor and the absence of through trunk streams forbid the supposition that it is a valley of erosion. There is very little direct proof of faulting, however; it must be inferred from the scarp, terrace, and tilted block type of topography which abounds on every hand, and also from an occasional repetition of lava beds above and below a scarp. Although the valley is a true graben, yet its tectonic features have been greatly modified by vulcanism and in a lesser degree by normal erosion. Great floods of lava have swept over the floor, the sides, and the

FIGURE 1.—THE UPPER SCARP AND PLATFORM: ESCARPMENT STATION

FIGURE 2.—THE MIDDLE SCARP AND PLATFORM: KIJABE STATION

THE RIFT VALLEY

approaches of the valley. The flows apparently have come from fissures which followed approximately the present course of the valley—fissures that in many cases may later have become the fault-planes of the great rift.

ESCARPMENTS AND PLATFORMS

The walls of the valley consist of a series of cliffs and platforms; they represent, respectively, fault-scarps and fault-block surfaces. The striking feature of the topography is its terraced character, exhibited on a titanic scale. The number of scarps vary. Sometimes there are but two; again there may be three, four, or even more; the normal number in this region is three. The number of scarps is determined by the development of subsidiary fault-planes, which branch out from the main fault and produce a larger or lesser number of fault-blocks, as the case may be. Where the railroad descends into the valley there are three scarps and two platforms. The total depth of the valley here is about 1,300 feet, divided between the three scarps as follows: Upper scarp, 350 feet; middle scarp, 700 feet; lower scarp, 250 feet. The height of any given scarp is not uniform, for the fault-blocks are often tilted, the throw at one end being greater than at the other; or there may be unequal subsidence in different portions of the same block. The slopes of the scarps are rarely very steep or precipitous; they usually permit the accumulation of soil. Some slopes are too steep to allow such accumulation, though talus frequently gathers at the base of such cliffs and it may reach far up the scarp face.

The soil supports a dense tropical forest on the upper heights, but vegetation becomes scanty toward the bottom of the valley, where arid conditions prevail.

The fault-planes are not straight, as a rule, but sinuous. The wall of the Rift Valley curves back and forth; the minor faults which produce the smaller blocks are generally curved, also. This curving produces blocks somewhat semi-lunar in shape, with their convexity toward the valley, as a rule. The blocks are widest in the middle and taper off at each end; generally the smaller blocks do not exceed a length of 2 or 3 miles. Frequently the blocks pitch away from the valley, but often they pitch toward it, or to the north or south. The eastern or Kikuyu wall is the steeper, and it has the more rugged and angular topography. The reason is that the rainfall is less on that side and there is far less accumulation of tuffs and other soft pyroclastics. The Nandi or west wall is the loftier, and originally the fault-scarps must have been more conspicuous there; but erosion has been so active on this side that it has worn down

the scarps to such a degree that they are often obscure. At the same time the platforms have been aggraded by detritus brought down from the heights above. The scarps thus tend to blend more or less with the platforms, and almost continuous slopes from top to bottom result.

Only the lower scarp, which lies below the region of greatest rainfall, is clearly defined. In the neighborhood of Lake Nakuru it is a steep, definite cliff, which forms the west bank of the lake.

THE VALLEY FLOOR

The Rift Valley is an area of accumulation; no streams drain it outwardly and no debris passes from it. All of the streams entering it from the encompassing escarpments bring in large quantities of detritus, and this is gradually spread out over the valley bottom, chiefly in the form of fans. Volcanic dust and coarser pyroclastic material have drifted across the valley and collected in many depressions. The valley floor thus tends to become debris-laden; it is a great plain of aggradation, interrupted by numerous volcanic cones and lava masses.

There are a number of depressions in the floor of the valley that are generally of diastrophic origin; in some cases the lower portions of these basins contain lakes. Volcanoes are numerous, especially to one side or the other of the valley near the escarpments. Lava flows are abundant in all portions. Some of the cones have large craters; thus Suswa has a crater nearly 4 miles across and the crater of Longonot is over 2 miles across. The lava flows may be narrow coulees or broad sheets; they belong to two distinct periods, as noted in the case of the plateau lavas. Kopjes are found separated from the parent sheet; in most cases these are due to faulting, though erosion has played some part in the separation.

The volcano of Longonot is typical of the Rift Valley cones. Its base is made up of massive lava-sheets arranged in rude terraces. This basal portion is deeply weathered and represents the earlier phase of vulcanism; then follow the less eroded younger lavas. The upper part of the volcano is a great ash and tuff cone, well dissected by deep ravines, which extend from top to bottom; parasitic cones modify the main cone to some extent. The last phase of vulcanism in the valley was explosive in type, and there are innumerable ash and tuff cones on the valley floor, most of them relatively small in size.

In the central portion of the valley, especially near Eburru, there are numerous steam jets, hot springs, gas vents, and such evidences of recent volcanic activity. In the region between Gilgil and Elementeita the recent lavas have flooded the country; nowhere else in the region is there

such an exhibition of vulcanism as here. Many of the massive ridges, such as the Eburru Range, are probably lava volcanoes, though their ridgelike form and the absence of cones may indicate fissure-flow genesis for these great masses.

LAKES AND LAKE BASINS

Three of the basin-like depressions which occur in the valley contain lakes, named respectively Naivasha, Nakuru, and Elementeita. These lakes have no outlets and all are alkaline, though Naivasha is but slightly so. Two of the lakes occupy basins which lie parallel to the main tectonic lines of the valley. Naivasha is in a round basin, and is less evidently of the foregoing type. All of the lakes are shallow, and they are gradually being filled by debris brought in by the intermittent streams that flow into them. Naivasha is the most shallow of the group, its greatest depth being but 35 feet and its average less than 20 feet. There has been, probably, a period of greater rainfall in the region within recent times and the lakes have covered a much wider extent of territory than they do now, though they have not stood long enough at any given level to form definite beaches or other shorelines. Near the southern end of Naivasha there is a steep-walled gorge about 125 feet above the present level of the lake. This was doubtless an outlet for the lake at one time, when the level stood at the higher elevation indicated by the surrounding lacustrine plains.

DRAINAGE OF THE VALLEY

The higher portions of the plateau on either side of the Rift receive a much more abundant rainfall than the valley bottom does, and the streams which head up on the heights have sufficient impetus to reach the floor of the valley, though they become intermittent in the arid climate of the valley bottom. Ravines are abundant on the valley sides, and they reach from top to bottom; they even notch the crest at intervals. The upper scarps are well dissected by ravines, but the lower ones are not, for rainfall steadily diminishes from the top of the valley to the bottom. The large ravines descend the higher scarp face and pass across the first platform in narrow V-shaped gorges 100 feet deep or so; on the second scarp and platform they retain the same general form and size; thence they pass down the lower scarp and out on the floor of the valley. At the outset the ravines, as they deploy on the valley bottom, are broad and shallow, but their sides speedily disappear and they merge into low alluvial fans, and their course is ended on these subaerial deposits.

The permanent streams are usually small and their valleys do not differ materially from the ravine type. The topography of the valley

walls is in a youthful stage, on the whole, and the indications are that the Rift is comparatively recent in origin.

FATE OF THE RIFT VALLEY

Since the Rift is a valley of accumulation, it might become filled with detritus in the course of time, but it would take long to obliterate it by this method. Erosion, however, is removing the divide which separates it from the Victoria basin, and that with rapidity. When this divide is taken away, the warm, moisture-laden winds from the Congo region, which now precipitate their contents on the western slope of the divide, will sweep across the Rift Valley and yield their rainfall to the eastern escarpment. Streams will then flow across the present Rift to the Nile basin, and the Rift Valley will be added to that great system of drainage. The east wall will then be attacked and retreat until a suitable gradient has been established to the Nile. By that time the Rift will largely disappear, perhaps leaving no trace of its existence. All that may be left to tell the story of its greatness and uniqueness will be the records of those who saw it in its pristine days.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 23, PP. 317-328 JULY 15, 1912

PROGRESS OF OPINION AS TO THE ORIGIN OF THE LAKE SUPERIOR IRON ORES[1]

BY N. H. WINCHELL

(*Read by title before the Society December 27, 1911*)

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The Report of Foster and Whitney

The celebrated report of Foster and Whitney on the geology of the Lake Superior land district, part II, 1851, was written, so far as concerns the iron ore of the region, by Prof. J. D. Whitney. It embraces the earliest discussion of this question, so far as the writer has observed, and can be summarized briefly as follows:

Quoting examples of the occurrence of crystals of specular and magnetic oxides of iron on the walls of volcanic craters, and in clefts and cavities where they could be attributed to sublimation from great heat, he is led to regard sublimation as one of the two factors in the production of iron ores of the Marquette district. Internal, as well as volcanic, heat was with Whitney a fundamental and active postulate in much of his geological reasoning. The other factor he supposed to have been simply igneous eruption, these oxides having been "poured out" from the interior of the earth in a plastic state. The former factor seemed to be required to account for the minuteness of the distribution of oxides, and to explain their banded structure in those cases where the oxide is closely incorporated in "metamorphic products," such as "jasper, hornstone, chert, chlorite, and talcose slate." It was the assumed "metamorphic" origin of these that made easy the assumption that the contained bands of iron ore were due to heat and therefore to sublimation. The actual molten

[1] Manuscript received by the Secretary of the Society January 9, 1912.

eruptive origin was attributed to larger masses of irregular shapes occupying preexisting depressions, or inclosed between strata that had been folded over them, or running in long dikelike lines across or among the associated strata. Thus *igneous action,* with its immediate products, was the primary agent. It is curious that Whitney, who was at that date an assayer and chemist rather than geologist, and whose reputation and skill placed him, in the judgment of the foremost authorities of his time, in the forefront of his profession, should have been willing to adopt a theory that violated so many of the principles of chemical science. The chemical impossibilities of this hypothesis have been shown amply in a former publication,[2] and the geological difficulties which it encounters are entailed in part by the erroneous fundamental chemical assumptions, and yet chiefly by insufficient and incorrect field observations. The errors of structural geology into which these pioneers fell, though numerous and sometimes vast, can be excused in the light of the newness of the problems and the inchoate ideas of Archean geology which were then prevalent. There was a profound non-appreciation of the importance of careful field studies, and of detailed description of the *facts as they exist.*

It is not intended here to discuss this hypothesis. It is necessary, however, in justice to Whitney, to give him credit for the origination of the primary idea of igneous forces and igneous rocks as the first cause of the ores of the region, whatever may have been the steps he trod to reach it, and whatever may have been the geological and chemical history that succeeded in order to get the oxides of iron into the condition in which we now find them. He appealed to sedimentation in a very limited way. He rightly rejected the idea of the sedimentary origin of the banding seen in massive jaspery ores on the tops of the conspicuous knobs, and rightly accepted it in the case of certain so-called "metamorphic strata," where the beds are of various widths, but with a conformable range and dip; and wherever some conglomeratic beds were found to be so interstratified, though containing traveled fragments of ore, they were believed to be in the same formation with the ore, and to have been formed by convulsive outbreaks of volcanism which broke the preexisting strata and furnished fragmental debris amenable to contemporary violent sedimentary distribution.

As there are two great fundamental causes for the origination of rocks, namely, *igneous action* and *sedimentation,* so, to a large extent, theories of the iron ore have oscillated from igneous eruption to aqueous sedimentation, since iron ore is one of the important components of the rocks of the earth's crust—not important because of its relative bulk, but because of its economic value and its wide distribution.

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[2] The iron ores of Minnesota. Bulletin VI of the Minnesota Geological Survey, 1891.

At a later date (1856), however, Whitney was more favorable to an aqueous sedimentary origin of some of the ores of Lake Superior. While not abating from his first view of the igneous origin of the most of the ore in its present condition, he said:

"There is still another form of deposit which is not infrequently met with in the Lake Superior region. . . . This consists of a series of quartzose beds, of great thickness, passing gradually into specular iron, which frequently forms bands of nearly pure ore, alternating with bands of quartz more or less mixed with the same substance. . . . These deposits seem to have been of sedimentary origin. . . . The iron ore may have been introduced either by sublimation of metalliferous vapors from below during the deposition of the siliceous particles, or by a precipitation from a ferriferous solution in which the stratified rocks were in process of formation." [3]

This suggestion of a ferriferous solution in a part of the waters of the ocean has been widely extended and adopted and appears in most of the latest literature, and has been so far expanded by some that it is made to operate even in all those ore masses in which no trace of sedimentary action could be seen by Whitney.

From the time of Whitney to the time of Irving, but few geologists entered thoroughly into the subject of the origin of the Lake Superior ores. None were found who disagreed seriously with Whitney, except Charles Whittlesey. Most of them, however, favored the sedimentary hypothesis rather than the eruptive. But frequently some modification or special action was found necessary in order to account for local conditions which were thought to be exceptional. Thus T. B. Brooks invoked the alkaline waters of thermal springs.[4] D. H. Browne would modify the sedimentary hypothesis, so far as it required the original deposition of crystallized siderite and calcite, by assuming that the deposit was hydrous oxide of iron and carbonate of lime.[5] Harrington suggested that, instead of chemical deposition and subsequent concentration, some of the stratified magnetites were deposited at first as iron sands, "just as they are forming in the Gulf of Saint Lawrence today, the material being derived from the disintegration of preexisting crystalline rocks." [6] Hunt believed that the oxides of iron, when abundant enough to constitute ore masses, were for the most part due to oxidation of the sulphide and the carbonate of iron, these having been formed as constituent parts of the stratified rocks.[7] Kimball added the idea of subsequent metamorphism in order to account for the specular form of oxide, but suggested that

[3] American Journal of Science, vol. xxii, 1856, pp. 38-44.
[4] Geological Survey of Michigan, vol. ii, 1873, p. 298.
[5] American Journal of Science, vol. ii, 1889, p. 299.
[6] Geology of Canada, 1873-1874, p. 194 *et seq.*
[7] American Association for the Advancement of Science, August 28, 1880.

the iron itself was due, not so often to direct sedimentation, but to "the decomposition *in situ* of basic eruptives by the dismemberment of silicates, followed by the concentration of ferric and magnetic oxides." This would exempt them from any intermediate or initial stage of sedimentation, and seems to fall in line with the laterite ores.[8] This fundamental suggestion is more important, perhaps, than Kimball imagined. Yet it was another form of the earlier idea of Whittlesey, who had argued that the Lake Superior ores were due to segregation and concentration under the operation of "metamorphism." Newberry, as well as Le Conte and others, while assuming sedimentation as the prime agent in the accumulation of these ores, appealed to the action of decaying organic matter as the chief force that extracted the iron in soluble form from preexisting rocks. It is evident, however, that no discussion of the ways and means of accumulation, whether chemical or mechanical, by sedimentation or segregation, whether by "metamorphism" or by the action of organic matter, touches the main question unless it distinctly involves the question of the source of the ore—that is, unless it points out the place of the iron in its primary condition in the rocks of the crust.

Charles Whittlesey's Theory of Segregation

To Charles Whittlesey is due, however, the earliest amply clear statement of the theory of segregation,[9] as follows:

> "If the metamorphism of the Laurentian and Huronian formations shall be regarded as an established geological fact, the separation of the oxides of iron from these rocks into veins, beds, and masses can be easily accounted for. All sedimentary strata contain the oxides of iron, and any agent powerful enough to change the crystalline form of the rock would bring about a concentration of their minerals. Metals, their oxides and salts, possess an inherent quality of segregation. Whenever the condition of the enclosing strata is such as to allow of motion among particles having the affinity of segregation, they must obey this affinity and become more concentrated. . . . The belief in a widespread, almost a universal, metamorphism of the rocks is rapidly gaining ground. In this mysterious but acknowledged force, which produces a new crystalline arrangement, have we not all the required agencies to produce masses of any mineral which existed in the strata prior to the change? Is not something more necessary to account for the result—some cause more universal than local chemical action?"

This suggestion of Whittlesey's, excluding his supposed cause of such segregation, completes the trio of natural forces and processes to which we must appeal. However vague and insufficient was Whittlesey's com-

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[8] American Institute of Mining Engineers, vol. xiii, 1884.

[9] Proceedings of the American Association for the Advancement of Science, 1867, p. 101.

prehension of the "metamorphism," of which he spoke, his claim that the iron ores of Lake Superior are the result of segregation, under some widespread impulse, contains the germ of one of the processes which have proved to have been concerned in the production of the great ore masses. This trio of nature in the production of these ore masses may be stated:

Eruption, *Whitney.*
Sedimentation, *Whitney.*
Segregation, *Whittlesey.*

The error has been that geologists have restricted their view, and often have presented *one only* of these processes as adequate to produce the results, and have extended their hypotheses over ore bodies, which are utterly repugnant to their initial ideas.

Whitney, for instance, when dwelling on the eruptive origin, transgressed chemical laws and the natural affinity of the elements; and, when representing the sedimentary theory, had to ignore some of the structural complexities. Whittlesey's idea, broadly embraced by him under the term *metamorphism,* as then understood, involved transpositions of matter in the rocks which are not known to have been caused by metamorphism; but that was due, let us believe, to the then miscomprehension, or vagueness, of the term. His germinal thought was *segregation*, and that has subsisted and has been found essential to a correct understanding of the history of the Lake Superior ores. Whitney never entertained, so far as observed by the writer, the theory of segregation, nor did any of those who followed in his track when he urged the eruptive hypothesis. His sedimentary hypothesis, however, has had numerous modifications, sometimes chemical and sometimes mechanical, and when chemical they have verged toward segregation, at least toward alteration. The most important of these suggested modifications is that of J. P. Kimball, who applied it, in the first instance, to the iron ores of Cuba,[10] but later extended it in part to the ores of Lake Superior. Thus he states clearly that "the large bodies of specular oxide, together with other associated ferruginous aggregates (in part of magnetic oxide), are secondary products from the decomposition of basic eruptive rocks," and "the other great bodies of ferric oxide in North America, like the Huronian deposits of Michigan and Wisconsin, are similarly derived from the decomposition of highly but less basic rocks of *metamorphic* and not of direct eruptive origin. Such stratified specular iron ore bodies are believed to owe their existence to the accumulation, by precipitation, of ferric oxide from basins of water receiving their drainage from such basic rocks." However far this be from Whittlesey's idea of "metamorphism," or from the

[10] American Institute of Mining Engineers, vol. xiii.

idea of metamorphism as now understood, it contains the germinal thought of Whittlesey's hypothesis, namely, segregation from ferruginous rocks that preexisted.

The Work of R. D. Irving

Irving was the first who made careful microscopical and chemical discriminations among the ores themselves and the associated quartz and other minerals. He was more exact than some of his followers, and more correct than all of his predecessors, at least along the lines which he investigated.[11] He did not treat of the titanic magnetites, and he did not distinguish structurally between the formations that carry ores of different ages. He hence reduced all the then known Lake Superior ores not only to one geological epoch, but to one chemico-sedimentary origin. Hence, as has been remarked already, he did not reach the *origin of the iron,* although he elucidated its present mineral condition and its structure. Irving's studies were based essentially on the jaspery hematites of the Archean at Marquette, the Vermilion ores not then having been discovered, and he believed the results of his work were equally applicable to the ores of the Penokee-Gogebic region. Irving's work proved to be epoch-making, as it furnished the basis of an important series of publications by the geologists of the United States Geological Survey, all of whom follow his main ideas, with the sole exception that latterly it was established to their satisfaction that the ores are of at least two different ages.

Irving specifically rejected eruption and metamorphism, and did not mention segregation; and, as stated by him, "it followed that we were restricted to some theory which should account for the precipitation of most of them essentially in their present conditions, with perhaps some slight internal rearrangement, or to one in which the production, from some form of sedimentary deposit, of the conditions now obtaining, should be assigned to metasomatic processes, carried out, in part at least, at a very remote period." Further examination and study led him to conclude that "these ferruginous rocks were once carbonates, analogous to those of the Coal Measures." This conclusion was hailed at once as tending to establish the *Azoic* as a great zoic age, in which flourished an abundance of life of different kinds, a prototype of the Carboniferous.

This conclusion was based on the actual existence of considerable quantities of carbonate of iron, associated with chemically deposited secondary silica in the terranes in which some of the ores are found. This he styled cherty carbonate, and this term figures largely in the

[11] American Journal of Science, vol. xxxii, October, 1886.

works of nearly all those who have more recently discussed the iron ores of Lake Superior for the United States Geological Survey.

J. E. Spurr's Investigation of the Mesabi Ores

As to the primary condition and origin of the iron embraced in this cherty carbonate, there was but little inquiry until the work of J. E. Spurr for the Minnesota survey on the Mesabi Range, who considered it to have existed in a silicate form in a mineral which he thought was a kind of glauconite, since named greenalite.[12] This green mineral was by him considered the source of all the iron ores contained in the formation, whether of ferric oxide or of cherty carbonate. He described what he considered the process of formation of the banded jaspers and the banded cherty carbonate. To this source, also, he referred the residuary clay-like deposits of silicate of alumina, or kaolin, some of the beds of which are from 70 feet to 80 feet in thickness. The agents that caused the decomposition of the greenalite were supposed to be oxygen, carbonic and other acids carried downward from the surface by atmospheric waters. In speculating over the nature of the original rock of the iron-bearing member, of which the greenalite appeared to be the only remaining representative, Spurr at the outset assumed an "excessively basic lava," but he abandoned that idea and adopted a sedimentary rock as the foundation of his hypothesis.

Sedimentation

Sedimentation, followed by profound metasomatic alteration and *segregation,* therefore, was the basis of the hypothesis argued by Mr. Spurr. In order to account for the greensand he assumed that there was, in the time of the Animikie, abundant organic life, thus supporting the assumption of Irving. The rocky matrix which surrounded the original glauconite grains he presumed was largely calcareous, a composition which rendered it liable to easy and rapid removal by descending acidulated waters. In order to account for the rounded forms visible in the altered iron-bearing rock after the elements of the rock had been removed by metasomatosis, Spurr appealed to a vague combination, which he called "granular brecciation, concretionary action, impregnation, and other forces." Had Mr. Spurr adhered to the idea with which he started out in his research, namely, "an excessively basic lava," he would have been much nearer the truth than he was. But he must be credited with an important chapter in the history of this long investigation when he

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[12] Bulletin no. x, Minnesota Geological Survey, 1894, p. 235.

discovered and pointed out the "glauconite," or greenalite, as one of the phases through which, as he supposed, the Mesabi iron ore had passed.

Since the date of Spurr's work (1894) this green substance has been the object of much study. Numerous chemical analyses have shown not only that it is not true glauconite, such as that derived from Foraminifera, but also that it is a mineral having such definite chemical proportions that it is deserving of specific designation. Leith gave it the name *greenalite* in 1903, in his report on the Mesabi range.

Divergence of Views between the Surveys

Among the divergences which early sprang up between the Minnesota Geological Survey and the United States Geological Survey, that concerning the origin of the iron ores of the Lake Superior region (especially those of Minnesota) is one of the most important. Those divergences are so numerous and so interlocked, and have become so profound, that many of the final conclusions are widely apart, and to one who reads either for the first time, the other appears too much like imaginary romance. Throughout the period involved in this investigation the responsible geologists have aimed to depend usually on fact or on legitimate inferences from fact, and, so far as the writer is concerned, he has never knowingly misrepresented the fact reported by another, nor the statements of another based on such fact. Unfortunately, however, his views and his statements have been peculiarly liable to misunderstanding and hence unintentional misrepresentation. This is so remarkable that the writer's theory of the agency of igneous rock in the origination of the iron ores has been distorted and discarded, although nearly allied to one that is set up in its place, and identical with it so far as they run parallel.

N. H. Winchell's Studies of Basic Igneous Rocks

In 1899 the writer became convinced of the immediate connection of basic igneous rock with the origination of the ores of Minnesota. This was published in 1900,[13] and it was the first published statement of that broad generalization. This connection involved igneous eruption, sedimentation, and segregation from the parent rock of the concerned iron ore. The igneous rock was shown to be originally in the form of basic lava, often consolidated in the form of obsidian. This rock was considered the first carrier of the iron. It was attacked by the waters of the ocean, torn into fragments by the action of the beach, and its debris distributed as detrital sediment. Cotemporary with this distribution, the oceanic water probably being hot, this igneous rock, whether lava or

[13] Final Report of the Minnesota Geological Survey, vol. v.

obsidian sand, was chemically changed, the most of the non-soluble ingredients being segregated into favorable locations, the soluble being taken into the oceanic waters and removed. Silica penetrated the uncrystallized or rhyolitic lavas and obsidian sand, giving rise not only to the taconite and jaspilyte masses, but also to the secondary quartzose grains, retaining their original shapes in the same manner that the silicified forms of trees and other vegetation are seen to be preserved in the alkaline, often volcanic, sediments of the Tertiary in the central western states. From the ferriferous solution of the near-by waters of the ocean, iron carbonate seems to have been precipitated in considerable amounts, such deposit becoming a constituent part of the cotemporary sedimentary strata, and in all probability, in favorable situations, ferric oxide was also deposited, as well as silica, these three forming alternating ingredients in the strata as now observed. The existence of iron-carbonate, however, is quite subordinate in Minnesota, so far as discovered, and this statement here depends mostly on reports that have been made by others as to its abundance on the south side of Lake Superior. It is almost lacking in the Vermilion and Cuyuna ranges, and in the productive parts of the Mesabi range it is replaced by carbonate of lime; on the eastern extension of the Mesabi, as at Gunflint Lake, it is more common. The greensand (greenalite), which has attracted so much attention, was shown, in 1900, to graduate in size into larger and larger masses, and in character into the taconitic "horses" and other residual forms of the primary lava. It never constitutes distinct strata.

In no case and in no particular has the writer abated from this view. Indeed within a few years past he has reinvestigated the subject, both in the field and by the aid of microscopic thin sections, and has found overwhelming additional evidence to confirm its correctness.[14] He has on several occasions since 1900 repeated this theory in the American Geologist and elsewhere. He has later shown that greenalite itself is not an oceanic precipitate, but a product of alteration of the original lava.[15]

In a recent publication by the United States Geological Survey[16] it is shown conclusively that the greensand could not have been derived by weathering and drainage from preexisting basic greenstones of the region. It had previously been shown by Leith that it is not of organic origin, as supposed by Spurr. It is also plain that as a silicate of iron it could not have existed in such large quantities locally in the water of the ocean without an immediate local cause. It became necessary, there-

[14] Proceedings of the Lake Superior Mining Institute, 1908, 1909, 1910, 1911.

[15] Proceedings of the Lake Superior Mining Institute, 1910.

[16] Van Hise and Leith: "The geology of the Lake Superior region," monograph lii, 1911.

fore, in the opinion of the authors, to find some other source for this green silicate of iron more immediate and more ready to furnish it. They reach the conclusion that the source of this green silicate of iron as well as the iron carbonate must have been some basic igneous rock. Basic igneous rock is specifically excluded from the cotemporary Animikie, although it is admitted that it "may really not be so distant as now appears" (page 507), and some consideration is given as to the cause of such exemption. But in the Keewatin the association of the iron-bearing rock with basaltic intrusion and extrusion is dwelt on at some length: this basic rock's agency, however, was its effect on the cotemporary sedimentation. It is not recognized in any case as the early bodily representative of any of the present iron masses.

In this result, so laboriously wrought out, the authors confirm, as far as they go, the conclusion of the writer in 1900. They would have rendered a greater service to geology, and would have confirmed every contention of the writer in 1900, if they had gone a step or two further and clearly designated in the case of the Animikie the igneous rock to which they appealed. The writer has shown, as already stated, that the bulk of the Mesabi formation consists of lava and fragmental obsidian. Near the bottom this igneous matter, especially that which is uncrystallized, was disintegrated *in situ* into its chemical elements, and these elements, where insoluble or difficultly soluble, have constituted the masses of iron, quartz, kaolin, and limestone which are found.

Some confusion and contrariety of opinion have resulted from a failure to study carefully the jaspilyte. It has been observed that the banding is bent in so close folding that it is impossible to imagine that the formation in which it lies has been so folded, and yet it is difficult to understand how the iron ore and jasper could have been so folded without an identical folding of the associated greenstone. On the other hand; it has been observed that sometimes, and even in immediate connection with the folded jaspilyte, there are plainly sedimentary bands of jaspilyte alternating with thin strata of other kinds of sediment, the latter usually being green, but sometimes of chemical silica or of hematite. This sedimentary origin being so evident, a hasty inspection has usually led to the idea of sedimentary origin of all the jaspilyte. The error has been in that assumption. J. D. Whitney only distinguished the two. It will be observed that where the contorted jaspilyte lies nonconformable in the midst of the greenstone, in nearly all cases there is on one side or the other (which may be taken as the *upper* side in the order of formation) a belt of greater or less width composed of strictly parallel strata made up largely of jaspilyte of identical composition, but interstratified with

other kinds of sediment. These strata are much less contorted or nearly straight and can be traced, without loss of their structural individuality or their chemical composition, for considerable distances. This fact is

FIGURE 1.—*Characteristic Surface of Jaspilyte: Soudan*

illustrated by the above figure, which is from a photograph taken from the north ridge at Soudan. Here the two kinds of jaspilyte are separated by the irregular line of nonconformity running between the two asterisks

seen in the opposite margins. The massive contorted jaspilyte is that which was formed by silicification of a mass of basic lava suddenly cooled by contact with the oceanic water, its fluidal structure preserved. The stratified noncontorted jaspylite is that which was formed by chemical precipitation consequent on the disturbance caused by the extrusion of the igneous rock now represented by the contorted jaspilyte. A further inspection shows that the contorted mass itself is composed of two parts, both of extrusive origin, one nonconformable on the other. That the stratified jaspilyte was of sedimentary origin is shown by its grading conformably into other sedimentary strata, such as green schist, slaty graywacke, and finally into coarser grit and graywacke.

But there is a third kind of jaspilyte, which sometimes becomes almost merchantable iron ore. It is also of detrital sedimentary origin, and in the vicinity of the other two kinds the individual detrital pieces may be very coarse, even large masses of jaspilyte of the contorted kind, as at the west end of the Lee hill at Tower, so sparsely mingled with other sediment that they may appear indigenous. This third kind of jaspilyte also has been the cause of perplexity to the field observer, but on careful examination over a wider area it has been found to graduate into finer and finer detritus and to pass into some of the stratified graywackes. It is needless to remark that this third variety of jaspilyte denotes a nonconformity in the rocks of the region, and that it belongs above the plane of nonconformity. At Tower, in the Lee hill, it is a part of the basal conglomerate of the Upper Keewatin and a phase of the Ogishke conglomerate, the great mines being all in the Lower Keewatin.

The same features and many of these jaspilitic facts have been observed in the Mesabi range, but on a smaller scale and with a greater distribution of detritus from cotemporary igneous rock.

It appears, therefore, that both on the Vermilion and on the Mesabi range the three forces that have been mentioned were jointly or successively in action to produce the Minnesota iron ores, and also it is certain that the ores were produced immediately after the extrusion of the igneous rock. These agents were:

1. Extrusion of basic igneous rock in immediate contact with oceanic water.

2. Sedimentary distribution of debris from the rock itself, and chemical deposition of ferric oxide as well as iron carbonate among the other sediments.

3. Segregation of the iron, the silica, the alumina, and sometimes the lime contained in the basic rock, into separate masses, making both residuary as well as constructive sheets in the stratification.

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SAPONITE, THALITE, GREENALITE, GREENSTONE[1]

BY N. H. WINCHELL

(Read by title before the Society December 27, 1911)

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SAPONITE

A soft, soapy earth, varying in color from nearly white to greenish and bluish colors, has been known for more than a hundred and fifty years. It has been called *soapstone* and *porcellanous earth*. It was found to fill cavities in rocks, and especially in those rocks that contain little or no potassium, such as basic trap rocks. It is a hydrous silicate of alumina and magnesia, essentially, but with a little iron and sometimes a little lime, and its optical elements have not been ascertained (System of Mineralogy). To this mineral Dana referred several species that were studied later and whose optical characters were determined, at least in part, and which had a similar origin, such as bowlingite, thalite, and some glauconite. Bowlingite was found to be derived directly from an alteration of olivine, one of the common magnesian minerals of basic igneous rock.[2] Thalite was found to have an internal vermicular structure and definite crystalline elements,[3] while glauconite as a term is divisible into true glauconite, carrying some potassium, and a potash-free variety which fills cavities in igneous rocks, and can easily be affili-

[1] Manuscript received by the Secretary of the Society December 13, 1911.
[2] American Geologist, vol. xxiii, 1899, p. 43.
[3] American Geologist, vol. xxiii, 1899, p. 41.

ated with saponite or with some of the species based on variations in "serpentine."

Thalite

Thalite was discovered and named by D. D. Owen when he examined the north shore of Lake Superior.[4] It was found to be essentially a hydrated silicate of magnesia and alumina, formed along the shore of the lake, from the alteration of basic igneous rock where the breaking waves dashed over the rock. It occupies amygdaloidal and all shapeless cavities, some of the masses being several inches across, and sometimes it is disseminated in fine granules through the mass of the decaying diabase. Its color is usually dirty white or gray, but within the rock it frequently is light green.[5] By Dana this mineral was placed under saponite, to which it has a chemical and physical likeness and a similarity of origin. It appears to have as much right to recognition as an independent species as several other species of a green color and soft and greasy feel, which are of like origin and composition, derived from the decay of basic igneous rocks, several of which have been embraced under the general term serpentine.

Greenalite

Greenalite is a similar mineral having almost the same composition and an identical origin. It is found to result from alteration of basaltic glass, or obsidian, an original constituent of the rocks of the Mesabi iron range.[6] It was named by Leith in a report on the Mesabi district in 1903,[7] but had been discovered by J. E. Spurr several years before, who regarded it as a non-potash form of glauconite. It is not only sprinkled through the original rock, where considerable alteration has taken place, and where the iron and the silica also have become segregated into individual masses, but it also serves as a general matrix, surrounding the other secondary ingredients. The original basic rock in this case was in the form of more or less rounded fragmental grains of obsidian, and the greenalite retains quite frequently the subglobular shapes of the fragmental grains. Leith has supposed the greenalite to have been a chemical oceanic precipitate, in the form of a ferrous silicate of magnesia and iron, from the waters of the cotemporary ocean, and to

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[4] Geological report on Iowa, Wisconsin, and Minnesota, 1852, p. 600.

[5] Final report, Geological Survey of Minnesota, vol. v, pp. 162, 168, 232, 238.

[6] N. H. Winchell: "A diamond drill-core section of the Mesabi rocks." Proceedings of the Lake Superior Mining Institute, 1910, 1911.

[7] Monograph xliii, U. S. Geological Survey.

have been the source, through alteration and segregation, of the iron ore of the region.

Serpentine

Serpentine, according to the latest determinations,[8] is not worthy of perpetuation as a name of a mineral species. It is rather a rock, and embraces mixtures of various greenish and usually ferrous, silicates of magnesia, or magnesia and alumina, combined with a large percentage of water, such as steatite (or talc), chrysotile, picrolite, antigorite, clinochlore, and sometimes pennine,[9] with other forms of chlorite. Serpentine is abundantly produced by the decay of the Archean greenstones, whether the greenstones were of igneous and crystalline nature and massive in structure or fragmental and stratified, in which latter case they should rather be called greenwacke.

Conclusions

From the foregoing it is apparent that the decay of a basic igneous rock gives rise characteristically to a group of green minerals, the composition of which varies from the silicates of iron and magnesia to silicates of alumina, iron, and magnesia, all of them hydrated and rather soft, and it is evident that the prevailing green color of the Keewatin greenstones is due to the predominance of these secondary minerals rather than to the existence of amphiboles and pyroxenes. The amphiboles indeed are plainly secondary after these greenish products, and can be seen to have been formed in microscopic spicules in the midst of the yellowish green isotropic field or to form directly by crystalline change from the original pyroxene.

If the question arises as to the whereabouts of the lime and soda, which were the alkaline elements in the original feldspars of the diabase, it can be answered by stating that they entered into the waters of the ocean, being more soluble, where they still remain, and that the existence of accessory quantities of lime in several of the secondary green minerals mentioned accounts for that portion of the lime which escaped such removal.

While a green product is characteristic of a change of basic igneous rocks undergoing weathering, it appears to be true also that the different insoluble elements when present in too large quantity for the secondary minerals are sometimes segregated by themselves. Thus were formed

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[8] Lacroix: Min. de France et de les colonies, part I, p. 417.

[9] Final report, Minnesota Geological Survey, vol. v, p. 329.

beds of iron oxide, and perhaps of iron carbonate, of silica, kaolin, and occasionally of marble.

The idea that these hydrous silicates of iron and magnesia or any of them may be formed by chemical sedimentation from the oceanic waters is apparently unnecessary and impossible. If it were proven that they are soluble at oceanic temperatures the question arises, Why would they not be carried away by the currents of the ocean along with the soda and most of the lime? Also, Why do they now have fragmental and, as on the Mesabi range, globular forms? Also, Why are they not found in distinct sedimentary sheets like marble and kaolin? And why do the associated chemical products, such as iron oxide and silica, present the same globular shape? It may be admitted that from an alkaline ocean there may have been chemical deposition of silica and iron oxide under certain conditions, but it is hard to understand why such deposit should in any case take the shapes which they and the greenalite exhibit on the Mesabi range. Since the iron ore and the silica, having the same origin and date, assumed identically the same shapes—that is, forms of detrital grains—it seems much more probable that a common cause controlled them all. There appears to be no possible hypothesis that will answer all the conditions but to assume that they took the shapes of preexisting detrital grains, and it follows from this that those grains were of such a nature that these secondary substances could be injected into them or produced by them. No detrital substance in the form of sand is known which is so easily altered as volcanic glass, or basaltic sand; and, in the light of the foregoing, it seems warrantable to infer that the original grains which gave shape to the greenalite and to the iron ore and to the rounded secondary quartz grains were grains of volcanic sand. Further, this hypothesis will not exclude the same alteration of adjacent sheets of lava and more or less crystallized trap, cotemporary with the production of these minerals in the volcanic sand; and in the case of considerable quantities of obsidian, which was not broken and distributed as sand, such masses would have been liable to the same change, namely, they would be likely to lose all their natural ingredients, maintaining their shape and their fluidal structure, and would present the banded structure seen in jaspilyte. Such masses are found not only on the Mesabi range, but in the ore bodies of the Vermilion and Cuyuna ranges.

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DIFFERENTIAL EROSION AND EQUIPLANATION IN PORTIONS OF YUKON AND ALASKA [1]

BY DE LORME D. CAIRNES [2]

(Presented extemporaneously December 30, 1911)

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INTRODUCTION

A study of the physiography of any district involves not only a consideration of the surface phenomena, but an examination of the materials composing that portion of the earth's crust and an investigation of the subterranean forces to which they have been subjected. A steeply inclined valley wall may merely indicate a youthful period in the topographic cycle; may be the result of glaciation; may be due to some inherent bedrock structure or the inclination of certain strata, or may even have been caused by recent faulting.

In investigating any physiographic problem, therefore, all the available evidence which tends to elucidate the physiography should be considered, no matter how superficial or deep seated may be the materials or forces involved. It is thus that the domains of physiography and general geology encroach and overlap—but always to their mutual ad-

[1] Published by permission of the Director of the Geological Survey, Department of Mines, Canada.

Manuscript received by the Secretary of the Society December 30, 1911.

[2] Introduced by Percy E. Raymond.

vantage. Nowhere has the writer found this better illustrated than in the district in which, during the past summer, he was engaged in connection with his regular field work for the Canadian Geological Survey. There in a single small area two contrasting types of topography are exhibited—one youthful, the other in a mature to old-age condition—and the differentiation is almost, if not wholly, due to the unequal powers of resistance which the dominant classes of bedrock in the district have displayed toward the various erosive activities to which they have been subjected.

The topography throughout the greater part of the area examined is characterized by low, generally well rounded, irregularly distributed hills and ridges, separated by wide flaring valleys; but included in this area is a belt which exhibits a well preserved high plateau, incised by numerous gorgelike depressions. The topography at the beginning of the present cycle is believed to have been very similar everywhere throughout the district, but now differs so widely in various localities, due to differential erosion.

Forces are also at work on the already nearly flat upland surface, tending to make this still more even and plainlike in contour than at present by a process here termed equiplanation.

Area

The area in which the writer was engaged during the past summer,[3] and which well illustrates the greater number of the points contained in this paper, extends along the 141st meridian (the Yukon-Alaska international boundary) between latitudes 66° 08′ and 67° 00′, or from the Orange fork of Black River northward to within about 30 miles of Porcupine River (figure 1).

Geological Formations [4]

With the exception of the Quaternary superficial deposits and a few isolated occurrences of igneous intrusive rocks, which, however, are too limited in extent to have had any perceptible influence on the general topography of the district, the main geological formations are mentioned in the following table:

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[3] D. D. Cairnes: "A portion of the Yukon-Alaska boundary between Porcupine and Yukon rivers." Sum. Rep. Geol. Surv., Department of Mines, Canada, 1911.

[4] For more detailed descriptions concerning the geological formations of this district than the one contained in this paper, see

D. D. Cairnes: "A portion of the Yukon-Alaska boundary between Porcupine and Yukon rivers." Sum. Rep. Geol. Surv. branch, Department of Mines, Canada, 1911 (in preparation).

Age	*Lithological characters*
Mesozoic (Probably largely Cretaceous)	Chiefly slates, phyllites, quartzites, sandstones, shales, dolomites, and magnesites.
Carboniferous	Chiefly limestones, cherts, and cherty conglomerates.
Ordovician-Silurian	Limestones and dolomites.

The Ordovician-Silurian limestones and dolomites constitute the bed-rock of the northern 20 miles of the area under consideration. These beds have an aggregate thickness of at least 5,000 feet and range from

FIGURE 1.—*Map of Yukon and Alaska*

Showing the area along the Yukon-Alaska boundary (141st meridian): which was geologically mapped and studied during 1911, by D. D. Cairnes, for the Canadian Geological Survey.

white through various shades of grey to almost black, and are even occasionally decidedly reddish or pink in color. These rocks are considerably folded, distorted, and metamorphosed, and are characteristically massive and crystalline in structure; but particularly in some of the darker members the bedding planes are in places still quite apparent. Fossils have been collected from these beds in several localities and have all been identified as being either of Ordovician or Silurian age.

The Carboniferous beds occur only in the southern portion of the district, where they outcrop throughout an area not exceeding 10 or 12 square miles in extent. They have an aggregate thickness of at least 1,500 feet and consist mainly of limestones, cherts, and cherty conglomerates, all three of which occur, in places, intimately associated. The limestones are generally quite crystalline and range from nearly white through various shades of grey to almost black in color, occasional reddish members being also noted. The upper limestone beds nearly everywhere contain chert pebbles, which, in places, constitute the cherty conglomerates of this series, and all gradations occur from a limestone including only occasional chert pebbles to a cherty conglomerate with a siliceous matrix and containing no perceptible lime. The chert pebbles are well rounded, and dominantly about the size of marbles, but some were noted as large as 1½ to 2 inches in diameter. In color most of the pebbles are grey, but occasionally quite black individuals were noticed. Beds of pure massive chert, similar in appearance to that composing the conglomerate pebbles, occur in places, but are not nearly so extensive as the limestone or conglomerate members. Fossils were obtained in a number of places from the limestone beds of this series, and all have been identified as being of Carboniferous age.

The Mesozoic beds extend over about two-thirds of the entire area under consideration, and consist chiefly of slates, phyllites, and quartzites, with also occasional sandstone, shale, dolomite, and magnesite beds.

The slates vary greatly in color, ranging from black to various shades of grey, green, red, or brown. They have everywhere a decidedly secondary induced cleavage, and generally break readily into thin plates from one to several feet in diameter and as thin as one-sixteenth of an inch, or even less. Probably the most noticeable and persistent beds are certain beautifully banded red and green members, the alternate bands of which are in places extremely thin and delicate and not more than one-fourth of an inch to 2 inches in thickness, and frequently much less, presenting thus a decidedly ribbon-like appearance.

The phyllites also vary considerably in color, but are generally some shade of grey, although occasionally greenish, brownish, or black members were noted. These rocks are distinguished from the slates by containing more mica, and being, generally, somewhat coarser textured. In places, the phyllites are much crumpled, folded, and distorted—isoclinal and even closed folds having been frequently noted in hand specimens. These rocks, also, wherever found, break readily along their cleavage planes, thus giving rise to the large thin slabs which are everywhere in evidence where these beds outcrop.

The quartzites range from nearly white to dark grey in color, and are typically massive, with a sugar-grained texture. Occasional beds, however, contain a certain amount of mica and chlorite, which, in places, are arranged, as the result of metamorphism, along definite planes between layers of purer quartzite, giving to the rocks a distinctly gneissoid habit.

The sandstones and shales were only rarely noted, and are the less metamorphosed equivalents of the slates, phyllites, and quartzites.

The dolomites and magnesites almost invariably weather rough and red, due to the considerable amount of iron ore they contain. The dolomite beds are, in places, as much as 200 feet or even more in thickness; but the magnesite beds rarely exceed 10 feet, and occasionally occur interbanded with the slates and dolomites in layers less than 2 feet in thickness.

An accurate estimate of the aggregate thickness of this group of rocks has not been made, since no place was found where the uppermost beds are preserved, and only small portions of the section could be observed at any one place. Moreover, on account of the metamorphosed condition of the rocks, it was difficult in most places to determine the dip and strike of the beds. The group is, however, at least 6,000 feet in thickness and may be considerably more.

The only fossils obtained from these rocks are poorly preserved, and were found within 100 feet of the underlying Carboniferous rocks; of these Dr. T. W. Stanton, of the United States Geological Survey, says: "My judgment is that these fossils are not older than Mesozoic and they may be Cretaceous, though there is no definitely distinctive Cretaceous fossil among them, and they do not seem to fall into any fauna known to be from that region."

In this paper, which is chiefly concerned with physiography, the Mesozoic and Ordovician-Silurian beds are mainly considered, as these are the dominant geological terranes, and have given rise to the two extreme types of topography exhibited in the district. The Carboniferous rocks are of comparatively small extent; consequently the limestones of this series, unless specifically mentioned, are not intended to be included by the term "limestones and dolomites," which is frequently employed with reference to the Ordovician-Silurian beds.

Differential Erosion

YUKON PLATEAU

The main area under consideration lies within and toward the northern edge of what is generally known as the Yukon Plateau physio-

graphic province, which in Alaska, Yukon, and northern British Columbia, stretches from the western edge of the Rocky Mountain system westward to the ranges of the Pacific Mountain system. This terrane trends northward through central northern British Columbia and continues northwesterly through Yukon and westerly through Alaska to Bering Sea, following, in a general way, the contour of the Pacific Coast line. This plateau province has been described by a number of geologists,[5] including Dawson, McConnell, Brooks, Spurr, Spencer, and Hayes, all of whom unite in the opinion that it represents a peneplanated and subsequently elevated surface; but it is to Dawson that we are indebted for the earliest recognition of the baselevel character of the Yukon Plateau region, as well as of the Interior Plateau of British Columbia, to which it is closely related.

Nearly everywhere throughout the Yukon plateau there is a decided uniformity of summit level; and in various portions of the province numerous hills and ridges occur, with flat or gently undulating tops, which evidently once constituted portions of a widespread surface having only slight relief. This surface formerly extended over the entire province; but extensive portions of the upland have now been destroyed, and in their place the valleys of the present erosion cycle exist.

The plateau is best viewed from a summit that stands at about the level of the general upland. From that viewpoint the observer will be impressed with the even skyline sweeping off to the horizon, broken only here and there by isolated, residuary masses, which rise above the general level. This plain-like upland, however, bears no relation to rock structure, erosion having beveled the upturned edges of the hard as well as the soft strata; in fact, this surface is entirely discordant to the highly contorted metamorphic rocks which make up much of the plateau; and for this reason is considered to be an uplifted and dissected peneplain produced by long continued subaerial erosion, during a period of crustal stability. The exact date of the uplift which terminated this long erosion cycle is somewhat in doubt, and is by different writers considered

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[5] G. M. Dawson: Trans. Roy. Soc. of Can., vol. 8, sec. 4, 1890, p. 13.

R. G. McConnell: "Report on the Klondike gold fields." Ann. Rep., Geol. Surv., Can., vol. xiv. 1903, p. 6B.

A. H. Brooks: "Geography and geology of Alaska." U. S. Geol. Surv., professional paper No. 45, 1906, pp. 36-41, 286-290.

J. E. Spurr: "Geology of Yukon gold district, Alaska." Eighteenth Ann. Rept., U. S. Geol. Surv., pt. iii, 1898, p. 260.

Arthur C. Spencer: "Pacific mountain system in British Columbia and Alaska." Bull. Geol. Soc. of America, vol. xiv, April, 1903, pp. 117-132.

C. W. Hayes: "Expedition through the Yukon district." Nat. Geog. Mag., vol. iv, 1893, p. 129.

FIGURE 1.—A STILL WELL PRESERVED PORTION OF THE PLATEAU SURFACE, 3,500 FEET ABOVE SEALEVEL

FIGURE 2.—THE GENERAL APPEARANCE OF THE UPLAND

Showing the steeply sloping character of the valley walls, and the decided shoulders everywhere in evidence at the contact between these and the old plateau surface

THE ORDOVICIAN-SILURIAN LIMESTONE: DOLOMITE BELT

to have occurred in late Miocene, Pliocene, or even early Pleistocene time.

The present discussion, however, is not particularly concerned with the origin of this plateau province. The purpose of the writer is to show that an elevated surface having only slight relief at one time extended throughout the tract now known as the Yukon plateau, and that the long, even, nearly horizontal summits, typical of many of the ridges, and the multitude of mountain summits, which in many localities are so characteristically flat-topped, and which everywhere rise to so uniform an elevation, all represent remnants of this former upland. Concerning these points, there is an abundance of positive, confirmatory evidence in almost any locality in the region under consideration, as has been noted by the various geologists who have studied this topographic province.

In the portions of the area along the 141st meridian here being considered, in which the Ordovician-Silurian limestones and dolomites constitute the dominant bedrock formation, the upland is well preserved, and considerable stretches of flat or but slightly undulating plateau occur at an elevation of about 3,500 feet above sealevel. This elevated surface truncates the various limestones and dolomite beds wherever these are unconformable with the almost horizontal upland surface (plate 15). The upland is dissected by numerous gorgelike depressions, which constitute the present day drainage channels of the area; and these valleys have characteristically, very abrupt walls, at the contact between which and the upland surface, decided shoulders representing topographic unconformities, are everywhere in evidence. It is manifest, therefore, that this upland was produced during a former topographic cycle, and consequently, previous to the entrenching of the present valleys, an unbroken, plainlike surface, well advanced in old age, must have extended over the entire district.

Outside the areas of limestone and dolomite beds, where the bedrock consists largely of Mesozoic slates, phyllites, quartzites, etcetera, although the plateau surface in many localities is almost or quite destroyed (plate 16, figure 1), still, in numerous places, ridges occur with remarkably straight, nearly horizontal summits, which are practically all in alignment, and these, together with the prevailing mountain summits, present a strikingly even skyline, showing the district to be a typical example of the thoroughly dissected peneplanated upland (plate 16, figure 2).

ERODING AND DISINTEGRATING PROCESSES

In passing from the northern part of the district, where the bedrock is composed prevailingly of limestones and dolomites, to the more southerly

portions, in which the Mesozoic rocks dominate, the change in topography is so abrupt as to suggest faulting. A close investigation, however, revealed no evidence of any extensive movements, but on the contrary resulted in the finding, in a number of places, of individual, unbroken, limestone and dolomite beds, which are traceable from the plateau upland out into adjoining thoroughly dissected Mesozoic portions of the area, where they underlie the slates, phyllites, quartzites, etcetera, thus proving conclusively that the fault theory does not account for the rapid change in topographic types or stages.

Moreover, wherever the Ordovician-Silurian limestones and dolomites occur at all extensively, the topography possesses the same striking plateau characteristics; but in all localities, where the dominant bedrock consists of Mesozoic beds, the thoroughly dissected upland topography is exhibited.

An examination of the resistance which these two classes of sediments offer to the attacks of the various eroding and disintegrating forces to which they are subjected, and of the rate at which they succumb to these, discloses the fact that erosive agencies work much more rapidly in the slates, phyllites, quartzites, etcetera, than in the limestones and dolomites, although the Mesozoic beds consist frequently of much harder and more indurated materials; and further demonstrates that this differential erosion quite sufficiently accounts for the differences in topography.

It is not intended in this short paper, however, to attempt a detailed consideration of all the various subaerial destructive forces that have combined to produce the present topography, but to deal only with a few striking points concerning the leading agencies, and especially those that have been mainly effective in accentuating the differences in the two types of topography in the area.

Wind action, for instance, although so powerful an eroding agent in some districts, and effective to some extent even in this northern, arctic region, has had its influence reduced practically to a minimum, since the greater part of the land surface is covered with forest, moss, or tundra, and all the superficial geological materials are frozen during all or the greater part of the year. The greatest extent of exposed bedrock occurs in the limestone and dolomite areas—and even there the uplands are largely covered with superficial deposits; but the rugged, jagged, valley walls are bared to the wind, which in such places accomplishes by abrasion a certain definite, although relatively small amount of erosion.

Chemical action is also more effective in areas of limestones and dolomites than in localities where the slates, phyllites, quartzites, etcetera, dominate, as the former materials are much the more soluble. Ordinary

FIGURE 1.—IN THE FOREGROUND, THE COMPLETELY DISSECTED CHARACTER OF THE TOPOGRAPHY

The hills rise rapidly toward the rear, as the limestones and dolomites are approached

FIGURE 2.—A TYPICAL RIDGE WITH AN ALMOST HORIZONTAL SUMMIT LINE

It is practically in alignment with the greater numbers of the hill and ridge tops in the district

DISSECTED CHARACTER OF THE TOPOGRAPHY IN AREAS OF THE MESOZOIC BEDS

surface waters, on account of their purity, have practically no chemical effect on siliceous and argillaceous sediments; but when containing even small amounts of carbonic acid gas or certain other impurities, dissolve limestones quite perceptibly. It is, however, to ground waters that the effectiveness of chemical action as an eroding agent is mainly due; these prevailingly contain various impurities that cause them to become very active solvents. The great amount of dissolved mineral matter which is annually carried to the ocean, either to be deposited there, or to remain in solution, is attributable largely to the ground waters; in addition, much of the mineral matter taken into solution is deposited either close to the point of its extraction or along the streams carrying it to the sea. The ground waters have no doubt played an important though largely unknown part in the subtraction of materials from the particular area under consideration, and in the limestone-dolomite belt, solution—both by the ground and surface waters—has apparently constituted one of the principal agents of destruction, as is indicated by the highly calcareous water in the area and by the disintegrated and partly leached character, in places, of the rock exposures.

The dominant weathering force throughout the area, however, appears to be frost action. In addition, expansion and contraction, due to atmospheric temperature changes, running water, nivation, and probably solifluction, are important subaerial destructive processes actively engaged in this district.

In this area, where throughout the greater part of the year the daily temperature changes are considerable, rock breaking and splitting proceed with great rapidity, especially in connection with the finely cleavable slates, phyllites, etcetera. In these rocks, water fills the multitude of spaces, including those along the cleavage planes; and when frozen, causes the rocks to break up readily into slabs, which in turn split into smaller flaky pieces. The more massive quartzites, limestones, dolomites, etcetera, are not so susceptible to this process, but are, nevertheless, considerably affected.

All the rocks are to a considerable extent fractured and broken by expansion and contraction due to temperature changes, and from this cause as well, the thinly cleavable beds suffer most.

Nivation,[6] or snow-drift action, has also played a somewhat important

[6] The term "nivation" was originally employed by Matthes and has later been applied by Hobbs and numerous other writers; see

F. E. Matthes: "Glacial sculpture of the Bighorn Mountains, Wyoming." U. S. Geol. Surv., 21st Ann. Rept., pt. ii, 1899, pp. 173-190.

W. M. Hobbs: "Cycle of mountain glaciation." Geog. Jour., February, 1910, pp. 147-163.

eroding part in some localities, particularly in those areas where the dominant bedrock consists of Mesozoic slates, phyllites, etcetera. During the seasons when snow only partly covers the surface, drifts tend to gather in numerous corners, and to remain in the various, irregular, somewhat protected angles, on the mountain slopes. During the day the water from the melting snow trickles from the lower edges of the drifts, and tends to move outward the fine material there accumulated. With lowering temperature during the night or on colder days, the water in the ground is frozen, and in expanding breaks up the remaining coarser material at the edge of the snow, and in this way provides a further supply of fines for the water to wash out when the snow and ice again thaw; thus the process proceeds. The drifts tend to gradually form steps up the mountain slopes, which, unless otherwise destroyed, yearly increase in size and afford protection for larger drifts each year, until eventually each replaces the one next higher. On numerous hillsides the successive steps are well formed and present quite a striking terraced appearance, but in most places these are removed by other erosive agencies as fast as they are formed.

An estimate of the rapidity with which erosion progresses in the slate-phyllite localities may be obtained from the appearance of the hillsides on which these rocks outcrop. In such places the surface has frequently a streaked appearance, as if some huge rake had been drawn down the slopes (plate 17, figure 1). The furrows represent the lines along which the streams of water trickled, removing, in so doing, much of the more finely comminuted rock material; the intervening ridges of unsorted waste also become reduced as the process continues. This raking is also often caused by melting snow, and at times, when rapid thaws or heavy showers cause water to be abundant on the hills, the talus is rapidly washed downward *en masse*, causing frequent accumulations of somewhat coarse waste to be distributed over the side hills (plate 17, figure 2). This rapid downhill movement of the waste, combined with the slow creep it everywhere possesses, might also be considered as a minor phase of solifluction[7] or land flowing, a process that has been so lucidly described by Professor Andersson.

By these various disintegrating and eroding processes the rocks of the hills are being gradually broken and comminuted and moved to within reach of the streams traversing the area, which annually convey vast quantities of such debris downstream toward Bering Sea.

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[7] J. E. Andersson: "Solifluction a component of subaerial denudation." Jour. of Geol., vol. xiv, 1906, pp. 91-112.

FIGURE 1.—"RAKING" IS HERE PRONOUNCED

FIGURE 2.—IRREGULAR ACCUMULATIONS OF WASTE THAT HAVE BEEN WASHED DOWN OVER THE SIDEHILL

EROSION PHENOMENA ON A CHARACTERISTIC SLATE-PHYLLITE SIDEHILL

In the limestone-dolomite belt the streams have, as yet, only succeeded in trenching a few gorgelike valleys, leaving extensive interstream portions of the upland still undisturbed; but to the south, where the dominant rock formation consists of the Mesozoic slates, phyllites, quartzites, etcetera, the streams have produced wide flaring valleys, and throughout considerable tracts have left no traces of the original plateau surface. The almost flat valley bottom of Black River, in the vicinity of the international boundary, is at least 5 miles wide, while those of some of its tributaries are over 2 miles in width.

The great relative difference in the amount of destructive work the streams have been able to accomplish in the different areas or portions of this one area is entirely due to the differences in the geological formations. The slates and phyllites, on account of their readily cleavable nature, are very susceptible to the mechanical activities of running water, and the intercalated quartzite beds being left exposed and often unsupported also readily fall a prey to stream action; also the numerous other disintegrating and eroding forces, previously mentioned, contribute a vast quantity of already comminuted material to the streams. Moreover, erosion is everywhere rapidly progressing except where the slopes have become sufficiently gentle to allow of the growth of a protecting mantle of vegetation.

In the limestone-dolomite belt the upland is prevailingly covered by debris, leaving only the valley walls exposed to disintegrating and eroding activities; and even there, although freezing and thawing and expansion and contraction have played a notable part, still, on account of the massive though not generally hard character of the rocks, these destructive processes have been so slow that solution appears to have been a comparatively important eroding force.

The arctic climate has also been an important factor in causing the topography in the different portions of this area to be so strikingly contrasted. A cold climate retards rock decay, rock solution, and practically all chemical activities, which are among the main forces by which the limestones and dolomites are affected; but rock breaking and splitting, to which even the hardest and most indurated slates and phyllites are so susceptible, are favored in regions where the daily temperature changes are great, which is the case in this area during the greater part of the year.

SUMMARY AND DEDUCTIONS

The area under consideration forms a part of what is believed to have been formerly a peneplanated and subsequently uplifted surface. The

upland constitutes throughout its extent a gently undulating plateau, with only occasional summits or ridges rising above the general level, and the plateau surface truncates equally the various geological bedrock terranes, regardless of their composition, structure, and other physical characters.

Following the uplift of this planated tract, erosive agencies were rejuvenated and began their work in the elevated terrane with renewed energy. Certain belts, in which the bedrock is composed, dominantly, of limestones and dolomites, have withstood erosive forces much better than other adjoining areas, where the bedrock formations consist prevailingly of slates, phyllites, quartzites, and related rocks, with the result that, in the limestone-dolomite belt, the topography is still in a youthful stage, and the plateau surface is so well preserved as to constitute the outstanding topographic feature of the area; whereas in the adjoining tracts the original upland has been either wholly or nearly destroyed and the topography is in a mature stage and rapidly approaching old age.

The reason for this differential erosion appears to be largely that the limestones and dolomites are relatively massive, compact materials; whereas the slates and associated rocks prevailingly contain innumerable seams, cracks, and spaces of various sorts, containing water and even allow of its circulating through them; and this water not only erodes the rocks, but when frozen causes them to split readily into innumerable thin slabs, rendering them an easy prey to all ordinary erosive and weathering activities. Further, since the slates, phyllites, etcetera, are thinly cleavable rocks, they are readily broken, due to temperature changes. In the limestone-dolomite belt or belts the waters either tend to run off rapidly through a few trunk channels or are held in a nearly dormant condition by the frost and more or less frozen debris of the upland.

Equiplanation

General

In the limestone-dolomite belt there still exist occasional well rounded monadnocks or rock residuals that rise above the general level of the upland surface: these represent the principal topographic relief that remained to break the monotony of this portion of the old peneplanated tract just previous to the uplift, which, as mentioned previously, is variously claimed to have occurred in late Miocene, Pliocene, and early Pleistocene time. The general upland bordering these residuals is in most places covered by accumulations of more or less frozen superficial deposits, the surfaces of which are either flat or but slightly inclined,

FIGURE 1.—A LOW ROCK ESCARPMENT

Shown at the contact between a typical limestone residual and one of the flat or nearly flat areas, which are underlain by partly frozen debris, and which characterize extensive portions of the upland.

FIGURE 2.—LIMESTONE RESIDUAL BLUFF

The flat, plainlike portion of the upland, which here supports a typically arctic vegetation and is underlain by partly frozen accumulations of debris, is distinctly seen to be encroaching on the limestone residual bluff on the right of the picture.

PLATEAU SURFACE IN THE LIMESTONE-DOLOMITE BELT WHERE EQUIPLANATION IS ACTIVE

and in most places support a considerable growth of a typically arctic vegetation. The contacts between these flat or nearly flat stretches and the residual masses are invariably abrupt, the residuals presenting to the debris areas rock fronts often nearly perpendicular and ranging from 2 to 50 feet, but generally only from 3 to 10 feet in height (plate 18, figure 2). The often nearly flat or but gently inclined surfaces at the top of these abrupt rock walls have, in places, a decidedly terrace-like appearance (plate 18, figure 1).

Upon investigating the relationships between the nearly flat surfaced debris accumulations and the adjoining rock walls of the residuals it was found that the limestones and dolomites are being slowly disintegrated, and to a considerable extent dissolved, to be later added to the adjoining, generally frozen, superficial materials that fill the existing bedrock depressions of the upland. By this process the accumulations of debris are continually increasing at the expense of the rocky summits. and thus the general plateau surface is becoming more and more plainlike in contour. This process is here termed "equiplanation."

DEFINITION

The term equiplanation (*L. aequus,* equal; *L. planus,* plain) is intended to include all physiographic processes which tend to reduce the relief of a region and so cause the topography to eventually become more and more plainlike in contour without involving any loss or gain of material to the area affected—that is, the amount of material remains apparently equal or is not increased or decreased by the plain-producing process or processes. Material may be expected from certain districts during the time equiplanation is in progress, but this export takes place quite independent of the equiplanation.

In the particular area along the Yukon-Alaska boundary line, described in this paper, portions of the upland surface that are already decidedly plainlike in character are becoming even more so by the erosion and disintegration of the residuals, and by the deposition of the materials derived therefrom into the intervening bedrock depressions, with the result that the general plateau surface is becoming more plainlike in contour, without involving any perceptible loss or gain of material to the areas affected.

EQUIPLANATING PROCESSES

In the area described the limestones and dolomites of the residual masses of the upland, as previously mentioned, are being slowly disinte-

grated and to some extent dissolved and conveyed out into the debris flats, where practically all the material held in suspension, as well as some at least of that in solution, is deposited. On account of the almost perpetually frozen condition of the superficial materials of the upland, the areas in which these materials occur are poorly drained, and consequently practically all sediments and precipitates deposited therein necessarily remain, having no means of escape. It is thus largely due to the arctic climatic conditions that the equiplanation process is here manifestly in evidence. A prolonged rise in temperature would cause the ice of the upland to thaw, with the result that the accumulations now filling many of the existing bedrock depressions would be washed out by the again integrated drainage system.

The rock terraces bordering the debris areas are largely of two types. In some cases these terrace fronts are of firm unbroken bedrock. These appear to represent antecedent forms that existed in the old peneplain and are still, but very slowly, being destroyed, owing largely to the compact nature of the rock constituting them. The majority of the terraces, however, are composed dominantly of talus, and are the resultant mainly of two forces, the relatively rapid forcing of the talus downhill by the frost and slow disintegration along the terrace front. The exposed limestones and dolomites of the residuals become in the course of time somewhat fractured, due largely to expansion and contraction of the rocks themselves and to the freezing and thawing of water filling the various open spaces they include. With further fracturing the rocks become broken, and the water filling the spaces between adjoining fragments, on freezing, forces the lowermost of these downhill. Expansion of adjoining talus members, due in warm weather to a considerable rise in temperature, also produces the same effect, only to a less degree. As the ice melts, or, on the other hand, as a high temperature falls slightly and the rocks contract, various blocks are left somewhat unsupported, hence move slightly downward in adjusting themselves to gravitation. This process continues until the various fragments are individually too far apart for water to readily fill the intervening spaces, at which stage the downward movement practically ceases. The talus blocks, having been somewhat rapidly pushed downhill, present a somewhat abrupt face, which remains practically stationary except for the slight amount of material that is annually removed therefrom by the various eroding and disintegrating processes previously mentioned; of which, solution, slow as it is, is one of the most active. Thus these rock faces, in many places, border the debris areas which are gradually encroaching on them, and if

allowed to continue undisturbed sufficiently long will include the residuals. Stream action and other destructive forces are, however, also engaged in destroying the uplands, and tend ultimately to again bring the district to a peneplanated or old-age condition.

In numerous places in the upland angular blocks of limestone, 1 to 3 feet in thickness, were noted projecting through the soil and fine waste, having been torn from the underlying bedrock and heaved into this position by frost action. These blocks gradually decompose, and in so doing contribute to the superficial materials of the upland, which in places resemble slacked lime, and occasionally are not unlike marl; but where the calcareous ingredients have been largely removed and only the impurities of the limestones remain, a rather typical soil or clay is exhibited. In places calcareous precipitates were also noted, which are being deposited from waters that are leaching the rocks elsewhere.

The processes just described are not thought to be limited to the one district here mentioned, but are believed to occur extensively in various Arctic regions. In addition, however, in many other districts and countries, sets of forces and processes quite different from these may cause equiplanation. In official reports on parts of southern Yukon[8] and northern British Columbia,[9] included in the Yukon plateau, the writer has described a similar process, although without naming it, which is attributable largely to nivation, and is causing portions of the upland there to become more and more plainlike. Also in many mountainous areas having interior drainage, plainlike surfaces tend to be produced by the double process of wearing down the ranges and filling up the basins.[10]

The plains thus formed will consist partly of worn-down rock and partly of built-up waste, and in their process of construction no gain or loss of material is involved. The mean levels of many such areas are slowly reduced by wind action, which exports, annually, varying amounts of material; but under certain conditions there is no export of material, and even when this occurs the equiplanation acts quite independently of the exporting process.

The equiplanating process, here described as occurring in northern

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[8] D. D. Cairnes: "Wheaton River district." Geol. Surv., Department of Mines, Canada (in press).

[9] D. D. Cairnes: "Atlin mining district." Geol. Surv., Department of Mines, Canada (in press).

[10] J. Walther: "Das Gesetz der Wustenbildung." Berlin, 1900.
E. Passarge: "Die Kalahari." Berlin, 1904.
A. Penck: "Einfluss des Klinas auf die Gestalt der Erdoberflache."
W. W. Davis: "The geographic cycle in an arid climate." Jour. of Geol., July-August, 1905.

Yukon and Alaska, is thus only a special phase of a general topographic phenomenon. In all its phases, however, equiplanation is characteristically different from all other plain-producing processes—such as constructional planation, peneplanation, glacial planation, etcetera—since in these, materials are either added to or subtracted from the areas affected. Equiplanation also differs fundamentally from peneplanation in that it operates regardless of sealevel.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

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CORRELATION OF THE PALEOZOIC FAUNAS OF THE EASTPORT QUADRANGLE, MAINE[1]

BY HENRY SHALER WILLIAMS

(*Read before the Society December 28, 1911*)

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INTRODUCTION

The first serious attempt to work out the geology of the Eastport region of Maine was made in the summer of 1884 by Prof. N. S. Shaler, then connected with the U. S. Geological Survey. The results of his explorations were published in a paper entitled "Preliminary Report on the Geology of the Cobscook Bay District, Maine."[2] At that time there was no detailed map of the region; the Coast Survey map did not appear until the year 1893. Shaler prepared a small map, giving the outline of the shores, bays, and inlets. In his paper the general northeasterly dip of the sedimentary beds was shown and the general succession of the fossiliferous beds along a line from the southwest to northeast across the area was established. A large amount of material, mostly in large pieces, was gathered; the fossils in most cases are casts of the interior or exterior and more or less distorted by compression after fossilization. The identifications were confessedly tentative, but a sufficient number of characteristic species were recognized to establish correlation of the faunas with the Clinton-Niagara-Lower Helderberg formations of New York; the uppermost beds on Moose Island were compared with the Devonian shale of Ohio on slender ground. No attempt was made to compare the species with the transatlantic faunas of corresponding age.

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[1] Manuscript received by the Secretary of the Society March 8, 1912.

[2] American Journal of Science, 3d ser., vol. xxxii, July, 1886, pp. 35-67.

Six years later, in 1892,[3] Dodge and Beecher published a report on the "Silurian formations of North Haven," and established for them a general equivalency with the Clinton and Niagara of the New York series.

In the summer of 1897 and 1898, I examined the formations of northeastern Maine (accompanied by H. E. Gregory, who studied the petrography), and from study of the fossils[4] established the presence of five formations, namely, *Aroostook limestone, Graptolite shales, Sheridan sandstone, Ashland shale,* and *Ashland limestone,* as containing species known in the Clinton and Niagara of New York. A sixth formation, the *Square Lake limestone,* was shown to be approximately equivalent to some portion of the Helderbergian. The seventh formation, the *Chapman sandstone,* was shown to have not only intimate relationship with the Becrafts or Lower Oriskany fauna of the New York province, but also to have much to connect it with the Downtonian or Tilestone formations of Scotland and Wales. The eighth formation, the *Mapleton sandstone,* was correlated as of Devonian age on the evidence of plants, but without attempting closer discrimination of its horizon. The ninth, the *Moose River sandstone,* in Summerset County (as had already been announced by C. H. Hitchcock in 1861)[5], was correlated with the Oriskany sandstone of New York.

Later, 1907-1908, the Gaspé faunas were critically studied by J. M. Clarke,[6] all of which were correlated by him as Devonian. The lowest of these, the fauna of the *St. Albans beds,* was shown to contain "a congeries of 51 species, of which fully one-half occurs in the Helderbergian faunas (Coeymans and New Scotland) to the southwest," which led him to conclude that there was at the time of their deposition an open channel connecting the Gaspé with the New York basin, in which the typical Helderbergian fauna lived.

The Arisaig (series), since the year 1868, has been recognized as holding faunas of Silurian age. Hall, Dawson, Honeyman, Ami, and others have given tentative correlations; but lately (1909) Twenhofel and Schuchert critically examined the faunas and correlated them as ranging from the Clinton to a time-equivalent of the Guelph of Interior America.[7] In that paper specific relation was also recognized with transatlantic

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[3] On the occurrence of Upper Silurian strata near Penobscot Bay, Maine. American Journal of Science, 3d ser., vol. xliii, 1892, pp. 412-418.

[4] Williams and Gregory: Contributions to the geology of Maine. U. S. Geological Survey, Bulletin No. 165, 1900.

[5] Agriculture and geology of Maine, 2d ser., 1861, p. 369.

[6] N. Y. State Mus. Mem. 9, 1908, Early Devonic history of New York and eastern North America, p. 250.

[7] American Journal of Science, 4th ser., vol. xxviii, 1909, pp. 161-163.

Upper Silurian formations ranging from Upper Llandovery to the Ludlow.

Thus for several years the evidence has been accumulating to prove that outside the general Appalachian axis, in the region covered by the State of Maine and the eastern Canadian provinces, more or less continuous sedimentation was going on during Silurian and early Devonian time. The faunas of these sediments are not identical with faunas of New York and the interior, but they exhibit intimate relationship with the transatlantic faunas of Paleozoic time.

During the preparation of U. S. Geological Survey Bulletin number 165 I was particularly struck not only with the general resemblance, but with the fact that the faunal combinations in Maine, namely, the generic associations of species in the successive faunas, bore a closer resemblance to the terminal Silurian beds of Great Britain than to the succession in the not-far-off district of New York.

From the knowledge I then had of the several faunas I concluded that the Cobscook Bay series, described roughly by Shaler, probably gave the best evidence of this relationship. This led me to urge the director of the Federal Survey to provide a topographic map of the Eastport region, so that it might be possible to work out in detail its very complex geology and paleontology. The result was that the Federal Survey, in cooperation with the State of Maine, prepared a topographic map of the Eastport quadrangle, Maine, which was published in the year 1908. In the summer of 1907, while it was in preparation, a party, consisting of E. S. Bastin, C. L. Breger, and myself began a geological examination of the region. During the years 1907, 1908, and 1909 we collected a full series of fossils carefully located stratigraphically. The field work is now complete. Mr. Bastin has the geological map in progress, and during the past year the fossils have been under investigation.

Although the preparation of the geological map and the description of the fossils are still quite incomplete, it has seemed to us that the geological section of the district, in its bearings on correlations between the two continents of America and Europe and on general problems of paleography, is of sufficient importance to warrant a brief statement of some of the more prominent facts already established by the evidence.

Structural Subdivision of the Rocks of the Eastport Quadrangle

Structurally the rocks are a confused mixture of igneous and sedimentary rocks, broken up by faults into numerous irregular blocks and

cut by numerous dikes and interbedded masses. Volcanic flows and ash beds constantly interrupt the sequence of the stratified and fossil-bearing sediments; but structurally, as well as faunally, the whole series is divisible into four distinct masses, namely:

1. A mass of slates and metamorphosed sandstones occupying in general the south corner of the area is separated from the rest of the series by a profound fault, which runs from a few miles south of the town of Whiting to Johnson Bay, north of Lubec. This fault has been traced across the boundary into southwestern New Brunswick. Faunally this mass contains the oldest fauna of the series.

2. The area on the west side of the quadrangle, including parts of the towns of Edmund and Dennysville, is covered by a mass of sediments and igneous rocks which do not appear to have suffered metamorphism. The mass is separated, however, by fault planes and probably by unconformity from the next higher mass.

3. The main interior mass of the quadrangle, the sedimentary beds of which contain a series of fossil faunas, ranging from purely marine below to estuarine beds at the top, is separated from the fourth mass by a distinct unconformity, as is shown by the sections in the region of the reservoir west of Perry village, where the uppermost beds of the Silurian rocks containing fossils are followed by the Perry sediments lying unconformably on them.

4. The Perry group occupies the northeast corner of the quadrangle, and is shown by its plant remains to be at least as young as Devonian. It lies unconformably on the series below.

Faunal Characteristics of the Sediments

Faunally the series is divisible into six fairly well defined geological formations.

Formations I and II (represented by the structural masses above described as 1 and 2) contain few diminutive fossils. *Plectambonites transversalis* (Wahln.) is found in both of them.

Zone I also contains *Monograptus* sp. indet., *Leptæna rhomboidalis* (Wilckens), *Atrypa reticularis* (Linné), and Spirifers of the *Sp. crispus* and *Sp. radiatus* types.

Zone II is known only by a single fauna in a soft mud-shale. It is distinguished by the presence of *Plectambonites transversalis* (Wahln.),

Bilobites bilobus (Linné), *Skenidum lewisii* (Davidson), and *Spirifer crispus* (Hisinger).

Thus faunally both of these zones are of Silurian age and probably not younger than early Niagara or Wenlock. It is not clear in what way they are structurally related to each other. The fossils are too few and too imperfect for determination of close correlation with other known formations.

Formation III is represented by a considerable number of fossiliferous outcrops containing a rich, purely marine fauna. The lower beds of this formation contain corals, not abundantly but frequent in occurrence, chiefly of the genera *Syringopora* and *Favosites*. I have not up to the present stage of my investigation discovered a trace of the genus *Halysites,* although Breger mentions it in his field notes. The following widely distributed species furnish the basis for correlation:

Atrypa reticularis (Linné), *Leptæna rhomboidalis* (Wilckens), *Spirifer crispus* (Hisinger), *Pentamerus galeatus* Dalman, *Meristina tumida* (Dalman), *Wilsonia* sp., *Cornulites* sp., *Dalmanites* sp.

Associated with these cosmopolitan types are *Spirifer elevatus* Dalman, *Strophonella funiculata* (McCoy), *Leptostrophia filosa* (Sowerby), the peculiar form called *Avicula danbyi* by McCoy, and *Monomerella woodwardi* (Salter), giving a complexion to the fauna unfamiliar to American paleontologists, though characteristic of certain transatlantic Silurian faunas.

This is the fauna listed by Shaler[8] in his paper of 1886 as of the "*Orange Bay* section." It was again reported by me[9] in 1905 under the station name of "*Whiting Bay,* No. 1440." In the latter list the resemblance of many of the species to well known Helderbergian species led to a misinterpretation of the correlation of the fauna. Having been strongly impressed by the wide fluctuation of characters of species in the Chapman fauna in northeastern Maine, I then gave too much weight to resemblances. Recent exhaustive study of the new material has convinced me that in place of having here a mixture of Helderbergian with Niagaran forms, we are really dealing with a series of transatlantic rather than American faunas.

Several of the British species have not heretofore been reported in American Paleozoic beds, although closely related forms have appeared in the Helderbergian faunas farther west. The species I listed in 1905

[8] Loc. cit., p. 54.

[9] G. O. Smith and David White: The geology of the Perry Basin in southeastern Maine. U. S. Geological Survey, Professional Paper No. 35, 1905, p. 22.

as *Spirifer* cf. *octocostatus* is Dalman's species *Spirifer elevatus*. "*Strophœdonta* cf. *Beckii*" of that list is *Leptostrophia filosa* Sowerby. "*Monomerella* cf. *ovata* var. *lata*" is the British form *Monomerella woodwardi* (Salter).

Two of the most characteristic species of the fauna are *Avicula danbyi* McCoy, found both in the Wenlock and Lower Ludlow in England (but hitherto not reported on this continent), and *Strophonella funiculata* (McCoy), which when Davidson described it was known by him only from the Wenlock.

Meristina tumida (Dalman) is also a typical transatlantic species closely resembling but distinct from *Meristina maria* Hall of the Waldron, Indiana, Niagara.

The presence, also, of *Pentamerus galeatus* Dalman makes it clear that the fauna is to be correlated with the Wenlock of Great Britain and the Middle Gothland of Gothland rather than with the Coeymans fauna of the Helderbergian series, where we are accustomed to meet that species in American rocks. Thus the species mentioned as well as the combination of species in the fauna makes it clear that Zone III of the Eastport series is to be correlated directly with the transatlantic Wenlock and Middle Gothland formations.

It is probable that the Coralline of Schoharie, New York, the Decker Ferry of New Jersey, and possibly the Selby dolomites of Clarke and Ruedemann are its near time-representatives west of the Hudson.

Formation IV contains a pure marine fauna. It may be divided faunally into two members. The lower member is rich in Brachiopods; the upper member has few Brachiopods and its fauna is characterized chiefly by Pelecypods and Gastropods.

There is a rather sharp distinction faunally between all of the outcrops of the lower member of formation IV and those of the underlying formation, III. This distinction may be briefly described by saying that the cosmopolitan species *Atrypa reticularis* and *Leptæna rhomboidalis* have dropped out. No. IV contains no representatives of the genera *Leptostrophia, Strophonella, Pentamerus,* or *Meristina,* and *Chonetes* of the *C. nova scoticus* type, *Dalmanellas* of the *D. lunata* Sowerby type, and Camarotœchia, not Wilsonia, are abundant in zone IV, while Wilsonias are abundant in III. As above stated, there is an abrupt change in the fossil contents in the midst of the formation; the upper member, though occasionally showing traces of the same Brachiopods as below, is characterized by its Pelecypoda and Gastropoda, the more frequently appearing of which are Grammysias, of the type of *Grammysia cingulata* Hisinger,

and *Platyschisma helicites* (Sowerby). The Ostracoda and Leperditia are also of frequent occurrence and often in great abundance in this upper member.

These characteristics of the generic association, the progressive change, and the identity of certain species in the faunas are illustrated by the passage from the Upper Ludlow into the Temeside groups of the typical section in England described by Elles and Slater,[10] but are not represented by any other series of beds on the American continent, so far as I am at present aware.

Formation V is distinguished from the lower formations by the entire absence of Brachiopods except the genus *Lingula* and the great abundance of a small Pelecypod we have previously listed as *Modiomorpha* cf. *subalata,* which on further study appears to represent *Anodontopsis augustifrons* McCoy. The formation is tied to the next lower formation by the continuance in great abundance in some beds of the *Leperditias* and *Ostracoda.* Distinct traces of *Pterygotus problematicus* Agassiz are also found in this formation.

This combination of characters recalls the terminal Silurian beds of Great Britain called Downtonian and Temeside rather than anything expressed on the interior of the American continent.

Formation VI is the *Perry formation,* the fossil plants of which have already been described by Mr. David White,[11] who has confirmed Dawson's correlation of it with the Devonian. This formation lies unconformably on the beds of formation V.

The above statements will suffice to indicate the facts of general interest which the detailed study of the Eastport faunas is bringing to light. The description of the species is in progress, many new species are being discovered and illustrated, and it would be premature to make any announcement regarding them at the present time. When the faunas are fully elaborated I hope to be able to establish the relationship existing between the Eastport faunas and the terminal portion of the Arisaig, the Silurian faunas of Penobscot Bay, and the Ashland faunas of Aroostook County, Maine. The facts already brought to light, however, make it clear that the series of beds here referred to as formations III, IV, and V have a more intimate relationship to the series of formations of

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[10] Highest Silurian of the Ludlow district of England. Quarterly Journal of the Geological Society, vol. lxii, 1906, p. 219.

[11] G. O. Smith and David White: The geology of the Perry Basin of southeastern Maine. U. S. Geological Survey, Professional Paper No. 35, 1905.

Great Britain described as Wenlock, Ludlow, and Downtonian or Temeside than to any of the standard series at present described on the American continent. By their fossil content and the order of sequence of the faunas they suggest a decided community of geological events and history for the two areas now separated by the Atlantic Ocean.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

DEVELOPMENT AND SYSTEMATIC POSITION OF THE MONTICULIPOROIDS [1]

BY E. R. CUMINGS

(*Presented before the Paleontological Society December 29, 1911*)

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INTRODUCTION

In my paper on the development of Paleozoic Bryozoa (6), published in 1904, I stated that the results brought out in that paper regarding the budding order of the initial growth stages of the bryozoan colony would afford a solution of the systematic position of the Trepostomata,

[1] Manuscript received by the Secretary of the Geological Society of America February 28, 1912.

or Monticuliporoids. In a second paper (7) I showed that the protoecium, or first exothecal stage of the primary individual of the colony, is very persistent in the primitive order of the Cyclostomata, and that it is also very strikingly developed in the Cryptostomata (*Fenestella, Polypora, Thamniscus,* etcetera). The exact form and morphological and developmental significance of this feature of bryozoan development were discussed at length in the latter paper.

During the past six years I have succeeded in obtaining the desired evidence in regard to the development of the Trepostomata, and have worked out in detail the development of a number of genera. In the case of *Prasopora, Phylloporina,* and *Callopora* the evidence leaves nothing to be desired. In *Peronopora, Rhombotrypa, Amplexopora,* and *Homotrypa* the protoecium has not been seen, but the budding order is definitely known. The methods of study have been described in my 1905 paper (7) and need not be repeated here.

Development of *Prasopora*

THE PROTOECIUM

The proximal portion of the primary individual of colonies of *Prasopora conoidea* Ulr., when perfectly preserved, consists of a circular disk of the type seen in the Cyclostomata and in *Fenestella,* etcetera (figures 1, 9, and 25). Its diameter is about 0.08 millimeter. As seen on the under surface (figure 9), there is a slight constriction between this disk and the remainder of the primary individual. When the section cuts through the upper portion of the protoecium and ancestrula, no such constriction is noted. In longitudinal sections (figure 23) the protoecium and ancestrula are seen to be continuous, although there is some evidence of a diaphragm between the two (figures 23, 26). There is a definite, very thin wall separating the protoecium from the substratum. The lateral and superior walls of the protoecium are thickened and present an appearance in the sections noticeably different from that of the walls of later zooecia. This same peculiar wall structure characterizes also the posterior walls of the ancestrula and primary buds. It is possible that the wall material of these primitive zooecia may have been different from that of later zooecia, although on this point the evidence is not satisfactory. In recent bryozoa, according to Barrois (1), the investment of the protoecium is actually different in texture from that of later zooecia. The appearance of this primitive wall substance in the Trepostomata, as seen under high magnification, is precisely the same as that of the proper wall of the initial portions of colonies of *Fenestella.*

It is clear and structureless, with no evidence of fibers, laminæ, or any of the characteristic features of the walls of ephebastic zooecia.

THE ANCESTRULA

The ancestrula is a tubular zooecium of the familiar type seen in the Cyclostomata. At first it is prone, lying along the surface of the substratum. Rising with gradual curvature from the substratum, it becomes straight, and at right angles to the base of the colony and extends directly to the upper surface of the latter. Diaphragms and cystiphragms make their appearance very near the point of origin of the ancestrula (figures 21, 23). It is evident that in the case of the Trepostomata only the lower portion of the long tabulated tube, seen in the figures, can represent the true ancestrula, since this tube was undoubtedly occupied by a succession of superimposed buds. In this feature consists, *par excellans,* the prime characteristic of the Trepostomata. The point of origin of the primary buds probably represents the distal end of the ancestrula, *sensu strictu,* since, after the analogy of recent Bryozoa, these buds should have arisen from the neck of the ancestrula. The posterior wall, and possibly the entire wall of the ancestrula, has the same peculiar texture as the wall of the protoecium (figures 1, 21, 22, and 23). The ancestrula has about the same diameter as the protoecium and is from one-half to two-thirds the diameter of the zooecia superimposed on it. No definite plane of demarcation between the ancestrula and the protoecium exists in the Trepostomata, such as is to be seen in *Fenestella* and the Cyclostomata. Their relations are altogether more intimate and primitive and seem to bear out my speculations in this regard published in my paper on the development of *Fenestella* (7).

THE PRIMARY BUDS

The position of the buds adjacent to the ancestrula (figures 1-6, 9, 25-27, 36, 37) is such as to make it certain that two lateral buds and one median bud arose from the latter. Two other buds (*e* and *f* in the figures) also lie adjacent to the ancestrula, but by a careful inspection of the figures it will be seen that the proximal ends of these buds are not in contact with the ancestrula, and that therefore they could not have arisen from the latter. The arrangement of these primary buds is precisely the same as in recent Bryozoa (cf. figures 10 and 28, and figure 40 of my 1904 paper).[2] These two buds (*e* and *f*) are also directed pos-

[2] In figure 10 (after Barrois) the left lateral bud is suppressed, only the median and right lateral buds being present. Otherwise the plan of budding is the same as that shown in figure 9. The buds surround the ancestrula somewhat more loosely than in *Prasopora* (cf. figure 17).

teriorly, whereas the other three are directed anteriorly—that is, in the direction of the ancestrula. In some of the sections another bud is seen between *e* and *f*, and probably originated from one of them. In the vertical sections (figures 20-24, 33, and 35) the fact is revealed that these two buds (*e* and *f*) arise at a level somewhat above the substratum, and serial sections show that they lap well past the ancestrula and arise to one side of it. As they attain the vertical ascending position, they swing in toward each other and ride over the superior surface of the protoecium (figures 3-6).

All of these buds give rise, as in the case of the ancestrula, to vertical successions of superimposed zooecia—the zooecial tubes of the colony. The upward extension of bud *e* (or *f*) is beautifully shown in figure 21 (also figure 35). Diaphragms and cystiphragms begin very near the point of origin of the tube. The wall structure of *e* and *f* is different from that of the ancestrula and like that of all later zooecia. The wall structure of the posterior portions of the lateral primary buds (2 and 3) is similar to that of the ancestrula and protoecium. In fact these buds and the protoecium are very sharply set off by this characteristic thickened wall from all of the buds posterior to them (cf. figures 14-16). I believe that the only interpretation of this feature is that this portion of the young colony was exposed while the lateral buds of the second and third generations were developing and before any of them came into contact with it. During this interval the exposed wall became more or less thickened and covered with foreign particles. This last fact is disclosed by the presence frequently in the sections of minute opaque particles lying in this region of the infantile zoarium (nepiasty), such as are commonly seen in sections through the surface portion of Trepostomata. The thickened posterior wall of the nepiasty is a very constant and eminently characteristic feature in sections of all the genera in which the initial region has been studied. Where the lateral buds of later generations envelop the nepiasty loosely, as shown in figure 17 (*Callopora* ?), this whole region is filled with foreign material.

THE SECONDARY BUDS

The exact origin of the two buds *e* and *f* can not be ascertained. From the analogy of recent Bryozoa they might come from either buds 2 and 3 or from the buds lying to the right and left of them (*z-z′*, figures 25-27). These two possibilities are shown diagrammatically in figures 26 and 27, where the solid arrows show the most probable arrangement and the broken arrows the alternative interpretation. The direction and charac-

teristics of these buds have already been described. Similar doubt exists as to the exact derivation of the buds marked *a, b, c,* and *d* in the figures. The most natural supposition is that *a* and *b* came from bud 1. The buds *z* and *z′* turn abruptly backward and inward toward the antero-posterior axis of the zoarium, in exactly the same manner as similarly placed buds in the recent Bryozoa.

Development of *Peronopora*

THE PRIMARY BUDS

It will not be necessary to take up in detail the development of this genus, since in all essential particulars it is identical with *Prasopora*. The protoecium has not been seen. Only two specimens showing the initial region of this genus have so far been obtained. The best of these is shown in figures 13-15. It is a nearly entire basal expansion and shows not only the initial buds and ancestrula, but the manner of origin of the median lamina that characterizes the genus. Three buds arise from the ancestrula, as in *Prasopora,* and are bounded by the characteristic thickened, structureless wall (*x-x′*). There appears to be an additional bud between the buds corresponding to *e* and *f,* as is also the case in some specimens of *Prasopora.* The beautifully symmetrical arrangement of the zooecia is shown in the diagrammatic drawing, figure 13.

THE MEDIAN LAMINA

The initial region of *Peronopora* for some distance from the ancestrula is identical with *Prasopora.* At a distance of 2 or 3 millimeters from the ancestrula, however, the zooecia in *Peronopora* begin to diverge more and more from an imaginary line, and a little farther out are separated into two juxtaposed regions by a definite median plate. This plate, the median lamina, is encountered at about the same distance from the ancestrula whether the section cuts vertically or horizontally through the initial region—that is, the zone in which the lamina makes its first appearance arches over the initial region in the antero-posterior vertical plane. A young colony a few millimeters in diameter may therefore be said to be substantially a minute *Prasopora.* The lamina itself seems to represent the suppressed axial region of an otherwise flabellate zoarium. In other words, instead of having a well developed axial region, consisting of the thin walled immature portions of many longitudinally directed long zooecial tubes, *Peronopora* has reduced the axial region to a double lamina, consisting of the juxtaposed proximal ends of oppositely directed, short zooecial tubes standing at right angles to the lamina. It is clear

that this lamina does not consist of a basal membrane or epitheca that has risen up into the colony.

Development of *Callopora*

THE PROTOECIUM

The protoecium of *Callopora* has the same form and appearance as that of *Prasopora,* described above. It has been seen in several specimens, two of which are figured (figures 7 and 8 = *Callopora dalei*). Both of these zoaria were growing on the shells of brachiopods, attached to the plicated outer surface of the shell, as shown in figure 39, where one of the shell plications is seen at the bottom of the figure. This accounts for the somewhat irregular arrangement of the primary buds, since they were not all developed on the same plane, but on an uneven surface. The protoecium in figure 7 was attached to a plication, most of which was, of course, ground away in sectioning down to the protoecium itself. The striated appearance of the section to the left of the protoecium is due to the presence of an excessively thin remnant of the brachiopod plication. This serves to call attention to the fact that the section reveals the absolute point of attachment of the primary individual of the colony. A similar feature is shown in figure 8 of another specimen. The relations of the protoecium and ancestrula are exactly the same as already described in *Prasopora.* The wall structure is also of the same type as in the latter genus.

THE ANCESTRULA

The ancestrula is well shown in figure 7. It is long, tubular, and very prone on the substratum. There is a very slight constriction between the ancestrula and the protoecium. As seen on the upper surface of the section, the walls of the two are perfectly continuous. The section shown in figure 8 was purposely left thick in order to show this feature. The surface shown in the figure is the lower surface, which was attached to the substratum. An exceedingly thin remnant of the brachiopod shell to which the protoecium and ancestrula were attached is present. By focusing up and down on this section the relations of the two can be very satisfactorily made out. The ancestrula is seen to be an obliquely placed, simple tube, with a disk-shaped proximal portion—the protoecium. The two have the same diameter, which is about 0.08 millimeter. As seen in figures 7, 8, 16, and 38, the initial zooecia in *Callopora* are all at first very nearly parallel with the substratum—that is, they lie, as in *Prasopora*, prone. For this reason the ancestrula is cut obliquely in

figures 16 and 38. These sections cut at about the same level as the section of *Peronopora* (figure 14) and present a very similar appearance.

THE PRIMARY BUDS

The lateral and median buds are shown in figure 8. Some sections indicate that the median bud sometimes failed to develop. This I believe to be the case in figure 16. The lateral buds were attached to the under side of the neck of the ancestrula, as in the recent Cyclostomata (cf. figure 30), and at once diverged rather widely from the ancestrula and from each other—that is, the radial arrangement of the zooecia, seen in cross-sections of the stems of *Callopora,* is very quickly attained (figure 38). The posterior wall of the ancestrula and primary buds has the same appearance and structure as in the case of *Prasopora* and undoubtedly for the same reason.

The section shown in figure 17 is from a specimen which could not be definitely referred to any genus, owing to the fact that the mature portion of the zoarium had been entirely broken away. It was a small ramose form, with rounded zooecia, diaphragms, and mesopores, found associated with *Prasopora* and *Phylloporina corticosa* at Cannon Falls, Minnesota. It is interesting in the fact that no buds whatever are in contact with the posterior portion of the ancestrula, and also in the fact that evidently four buds rather than three issued from the ancestrula.

Development of *Phylloporina corticosa*

The initial stages of this species are so nearly identical with those of *Prasopora* that they do not need extended description. A comparison of figures 29 and 25 will satisfy any one of this. The protoecium is large, and beautifully shown in figure 29 (see also figure 18), which is drawn with the utmost possible fidelity to the original section. The ancestrula and primary buds are all very prone, more so than in any other form studied. The arrangement of the primary and secondary buds is the same, point by point, as in *Prasopora.*

The chief interest attaching to *Phylloporina corticosa* is in the complicated fenestriate zoarium which it builds. So aberrant is it in this respect that Ulrich very naturally referred the species to the Cryptostomata, placing it in the genus *Phylloporina.* In 1904 (6) I stated that the species belongs to the Trepostomata. In 1905 (7) I figured the section of the initial region, shown here again in figure 29, and called attention to the presence of the protoecium. The identity of the initial growth stages with those of *Prasopora* is sufficient to show that the species is a true trepostome. In figure 19 of another specimen is indicated

somewhat diagrammatically the manner of origin of the remarkable Fenestella-like branches or rays. The first indication of these rays is the tendency of certain zooecia to arrange themselves in parallel pairs at rather regular intervals, between which the arrangement is still somewhat irregular. The interzooecial walls of these parallel juxtaposed zooecia next become somewhat thickened, giving rise to the ill defined vertical median lamina of the sinuous anastomosing branches of the colony. A young colony in which the infundibular superstructure has not begun to arise presents a curious resemblance to one of the star-shaped maculæ of a *Constellaria.* The remarkable features of this species indicate very impressively how tenuous after all is the line between the Trepostomata and the other orders of the Bryozoa. Ulrich (13, 14) has pointed out at sufficient length the affinities of the species with the Cryptostomata. Its affinities with the Trepostomata are conclusively shown by its mode of development.

Development of *Rhombotrypa*

Figure 40 shows a transverse section cutting somewhat above the protoecium of a young colony of *Rhombotrypa quadrata.* The general arrangement of the zooecia is the same as in the other genera studied. The ancestrula gives rise to two buds. The primary buds and ancestrula are set off from the posteriorly directed buds by a thickened wall, as in all other genera. A noteworthy feature of this section is the presence of acanthopores in the initial region. They are not present in the mature portion of colonies of this species. This may be taken to indicate the affinities of this genus with *Amplexopora.*

Development of other Genera

Several sections have been obtained of *Amplexopora septosa,* showing the initial region. Their appearance is the same in all essential respects as that shown in figure 40 of *Rhombotrypa.* Acanthopores are present in abundance, even in the primary buds.

A few sections show the initial region of what appears to be a species of *Homotrypa.* The arrangement and budding order are the same as in *Prasopora,* and the thickened posterior walls of the ancestrula and primary buds are exceptionally well shown.

Discussion and Conclusions

The form and structure of the primary zooecium of the colony of the Trepostomata and the arrangement of the buds and their derivation

have all been shown to be in strict agreement with undoubted Bryozoa. The presence of the protoecium alone is practically conclusive on this point, since it represents a definite stage in the metamorphosis of the larva, not represented in the corals. In the latter the development from the instant when the planula becomes sedentary is direct. Again, the restriction of budding to the neck region of the ancestrula finds no counterpart in the corals, where buds come off symmetrically all around the primary individual of the colony (cf. figures 9 and 12). This feature of coral budding is beautifully shown in the figure of *Pleurodictyum*, reproduced herewith, and still more clearly in the diagrams of *Michelinia* given by Beecher (3). It also characterizes the recent red coral (*Corallium*), according to Lacaze-Duthiers (8), and *Renilla*, as described by Wilson (15). Bernard mentions symmetrical budding in *Turbinaria* (4) and in *Montipora* (5). No doubt it occurs generally in corals, as the construction of the coral polyp would lead us to expect. The literature of corals is, however, for the most part singularly silent on the subject of early colonial development.

In view of this conclusive evidence from development in regard to the systematic position of the Trepostomata, it is scarcely necessary to revamp the evidence variously presented by Ulrich (12), Lindström (9), and others on this point, or to review the adverse opinions of Nicholson (10), Sardeson (11), and others. Lindström's views do receive a new interest from the present studies. While I do not believe with him that there is any direct relation between *Ceramopora* and *Monticulipora*, he should receive the credit for having attacked the question of systematic position from the right direction and for having made suggestions of great value. Had his suggestions been carefully followed up, the mystery of the Trepostomata would have been cleared up long ago.

Ulrich has given a powerful presentation of the evidence of morphology bearing on the systematic position of the group, and recent studies of Bassler (2) and myself have materially strengthened this class of evidence. I have, for example, found that communication pores are present in a considerable number of genera, as *Dekayia*, *Batostoma*, *Bythopora*, *Callopora*, *Eridotrypa*, *Monticulipora*, *Nicholsonella*, and *Peronopora* in addition to the long known cases of *Homotrypa*. The evidence on this point is now in press.

A word may be said with reference to the views of Sardeson. First of all, he stakes his case on the proposition that the Trepostomata and Cryptostomata are very intimately related. This is perhaps more than the most devoted students of the Bryozoa would be willing to grant. But, accepting it at its face value, his case for the coral affinities of the

two groups vanishes with the certain evidence presented by me in 1904 and 1905 as to the intimate relations between the Cryptostomata and the Cyclostomata. The wonderfully typical development of the protoecium in *Fenestella,* together with the typically bryozoan order of budding and the morphology of the ancestrula and primary buds, leave no doubt on this point.

The morphology of the primary individual of the Trepostomata colony suggests interesting relationships with the Cyclostomata. I believe, however, as I stated in 1905, that the two orders are cognate and do not stand in a linear relation one to the other.

In figure 32 of the present paper is shown the interesting fact that in *Prasopora* the arrangement of the zooecia in the maculæ is the same as in the initial region of the colony This section cuts at the level *m-m′*, figure 20—that is, far enough above the ancestrula to show the normal ephebastic characters of the colony. This arrangement of zooecia in the maculæ has not yet been fully investigated. It lends some support to the view that maculæ and monticules are suppressed or aborted branches—that is, there is a rhythmic tendency to branch—but usually the process stops with the establishment of the appropriate arrangement of the zooecia, which is the same as the arrangement at the base of the primary stock of the colony. It may go slightly further and give rise to an elevated group of zooecia, or monticule.

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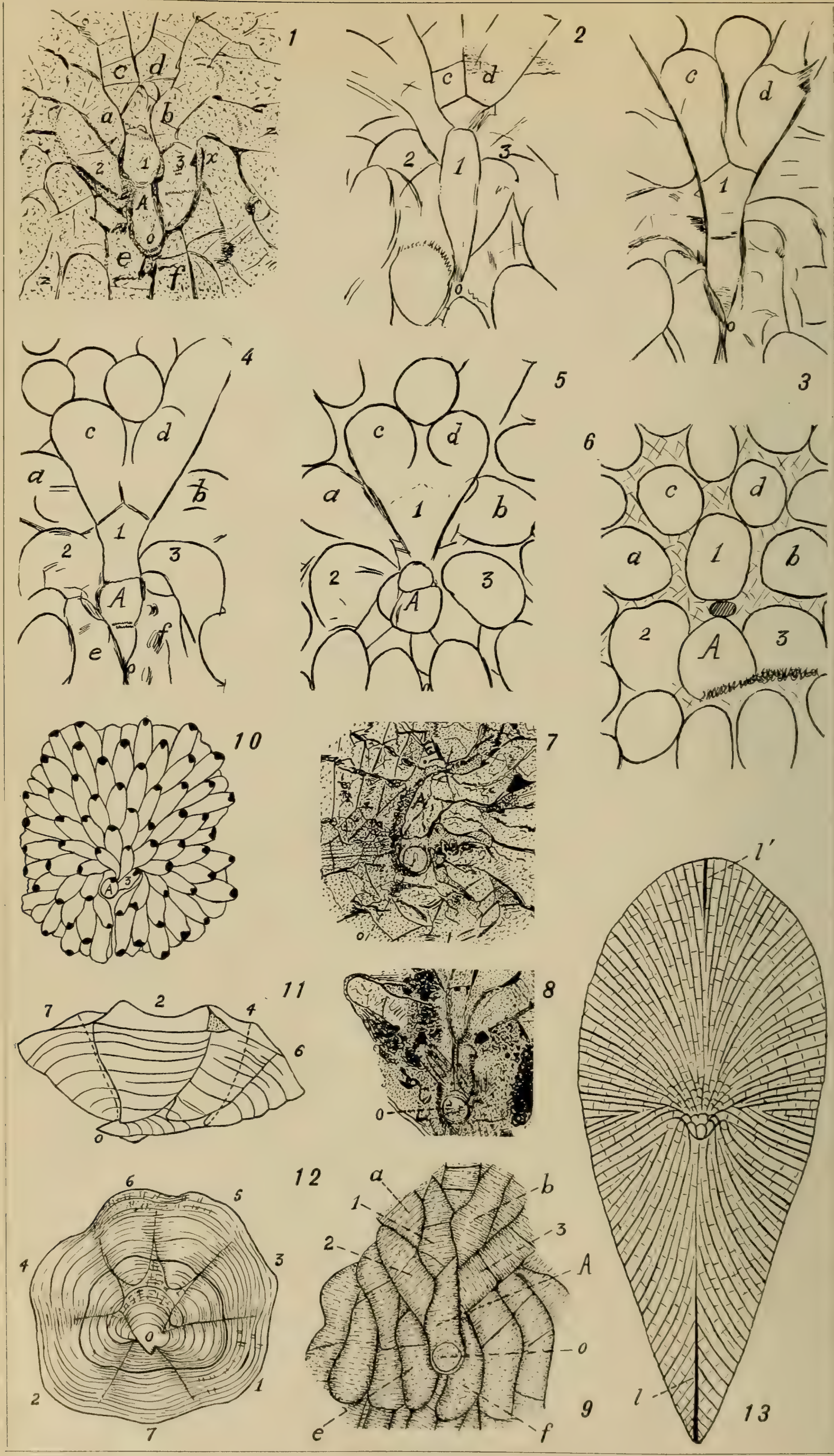

DEVELOPMENT OF THE MONTICULIPOROIDS

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Explanation of Plates[3]

Plate 19.—Development of the Monticuliporoids

Figures 1-6.—*Transverse serial Sections of a Colony of Prasopora conoidea Ulr.*

Figure 1 is the finished section, and is at the level indicated by the line *r-r′*, figure 20. Figure 4 is about the level *p-p′*, figure 20, and figure 5 is at the level *n-n′*, figure 20. Figure 6 is slightly higher. These figures are selected from a set of 18 drawings, representing 18 successive levels between *r-r′* and *m-m′*, figure 20. A section at the level *m-m′* is similar in all essential respects to figure 31. Figures 3 and 4 show how the buds *e* and *f* swing in toward each other, and thus come to rest on the protoecium, which lies beneath the point marked *o*. All figures × 43. (106-10.)

Figure 7.—*A detailed Drawing of a transverse Section through the initial Region of Callopora dalei (M.-E. and H.).*

Showing the protoecium and the ancestrula. A slight constriction between the two will be noted. This constriction is not observed on the upper surface of the specimen—that is, if the slide be turned over and the microscope accurately focused on the upper surface of the section the walls of the ancestrula and protoecium will be seen to be continuous. × 43. Cut No. V, Tanner's cr. Mount Hope formation. (118-3.)

Figure 8.—*Transverse Section of the Protoecium of another Specimen of Callopora dalei.*

The lateral buds come off on the under side of the ancestrula, well back toward the protoecium, as in recent *Tubulipora* (cf. figure 30). × 43. Cut No. V, Tanner's cr. Mount Hope beds. (118-11.)

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[3] All drawings except figures 10, 11, 12, 13, 28, and 30 were made with the camera lucida. Figures 10, 28, and 30 are after Barrois and figures 11 and 12 after Beecher. Figures 32-41 are microphotographs of the original sections.

Letters and numerals having the same meaning for all the figures:

a, b, c, d, e, f, buds of the second or third generation.

z-z′, buds probably of the second generation, from which the buds *e* and *f* are supposed to be derived.

A, Ancestrula.

o, Protoecium.

x-x′, Thickened wall of the ancestrula and primary buds.

1, Median primary bud.

2, Left lateral primary bud.

3, Right lateral primary bud. (These numbers do not apply to figures 11 and 12.)

FIGURE 9.—*View of the initial Region of an unusually well preserved Specimen of Prasopora conoidea, as seen by reflected Light.*

Note that the point (initial portion) of the bud *e* is not in contact with the ancestrula and therefore could not have originated from it. × 43. Cannon Falls, Minnesota, Phylloporina bed. (106-16.)

FIGURE 10.—*A young Colony of the recent Bryozoan Schizoporella, after Barrois.*

Showing the similarity of arrangement of the zooecia to that seen in figure 9. × 10.

FIGURES 11 AND 12.—*Side and basal Views of a young Colony of the coral Pleurodictyum lenticulare, after Beecher.*

Showing the totally different form and arrangement of the initial individual of the colony and the primary buds from that shown in figure 9. The buds appear in the order of the numerals. Note that seven buds arise from the initial individual and are symmetrically arranged about it. × 1¾.

FIGURE 13.—*A diagrammatic Drawing from a Photograph of a Section through the initial Region of Peronopora pavonia (D'Orb.).*

Showing the ancestrula and primary buds and the arrangement of the zooecia in the basal expansion of the colony. The origin of the median lamina is shown at *l* and *l'*. × 9. Cut No. VIII, Tanner's cr. Upper Lorraine. (104-1.)

PLATE 20.—DEVELOPMENT OF THE MONTICULIPOROIDS

FIGURE 14.—*Initial Region of Peronopora pavonia (same Specimen as Figure 13).*

This section is too high in the colony to cut the protoecium, but shows the ancestrula and primary buds. The conspicuous thickened wall bounding the ancestrula and primary buds is shown at x-x'. × 43. (104-1.)

FIGURE 15.—*Semi-diagrammatic Drawing from Figure 14.*

FIGURE 16.—*Transverse Section through the initial Region of Callopora ramosa (D'Orb.).*

At a level similar to that of figure 14. × 43. Cut No. VIII, Tanner's cr. Upper Lorraine. (106-17.)

FIGURE 17.—*Transverse Section through the initial Region of a Callopora (?) from the Phylloporina Bed, Cannon Falls, Minnesota.*

In this specimen there was a void immediately posterior to the protoecium as in the recent *Discoporella* (cf. figure 41). This clearly shows that no posteriorly directed buds arose from the ancestrula. × 43.

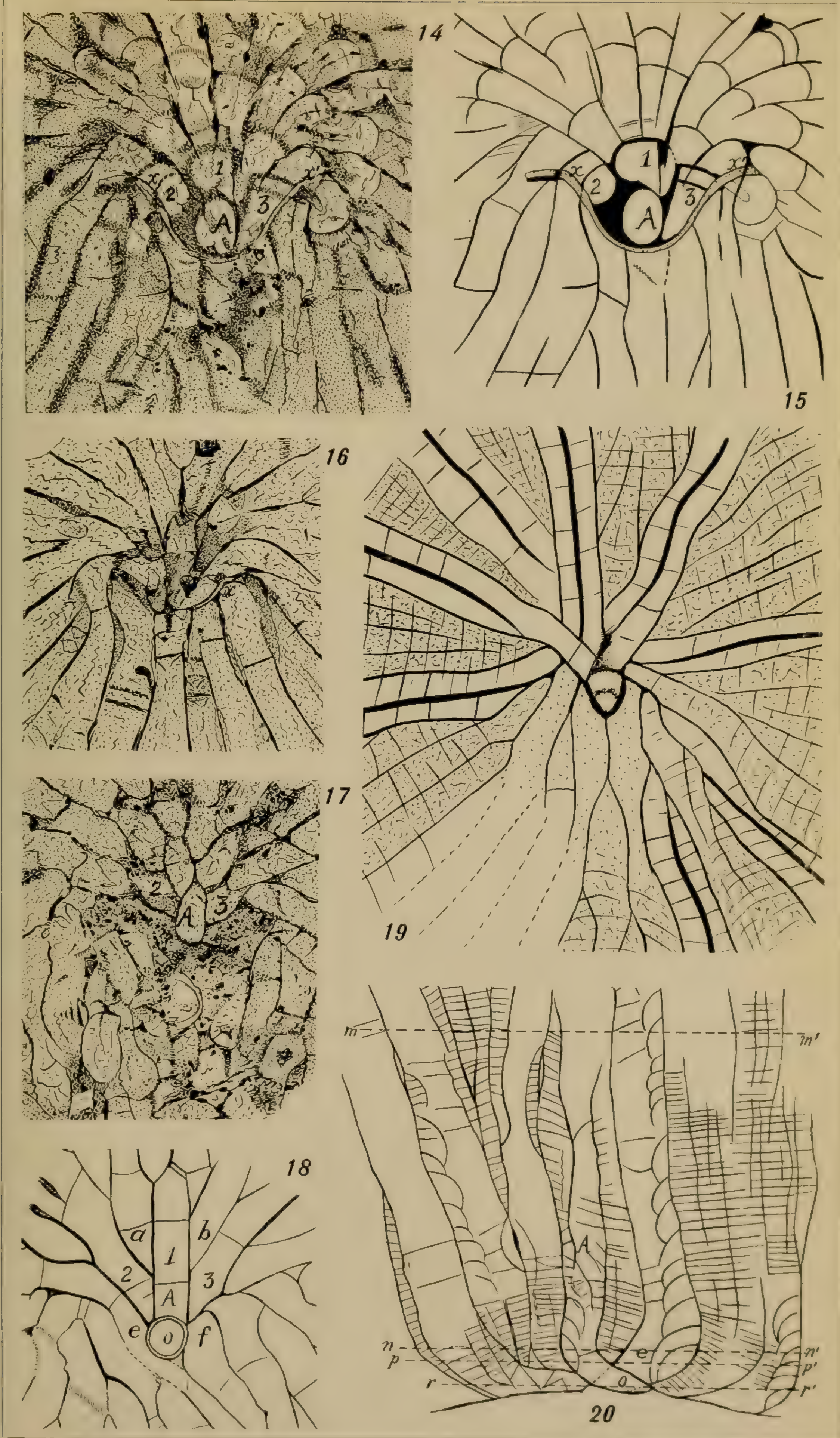
FIGURE 18.—*Semi-diagrammatic Drawing from Figure 29. × 43.*

FIGURE 19.—*Diagrammatic Drawing of the initial Region of Phylloporina corticosa Ulr.*

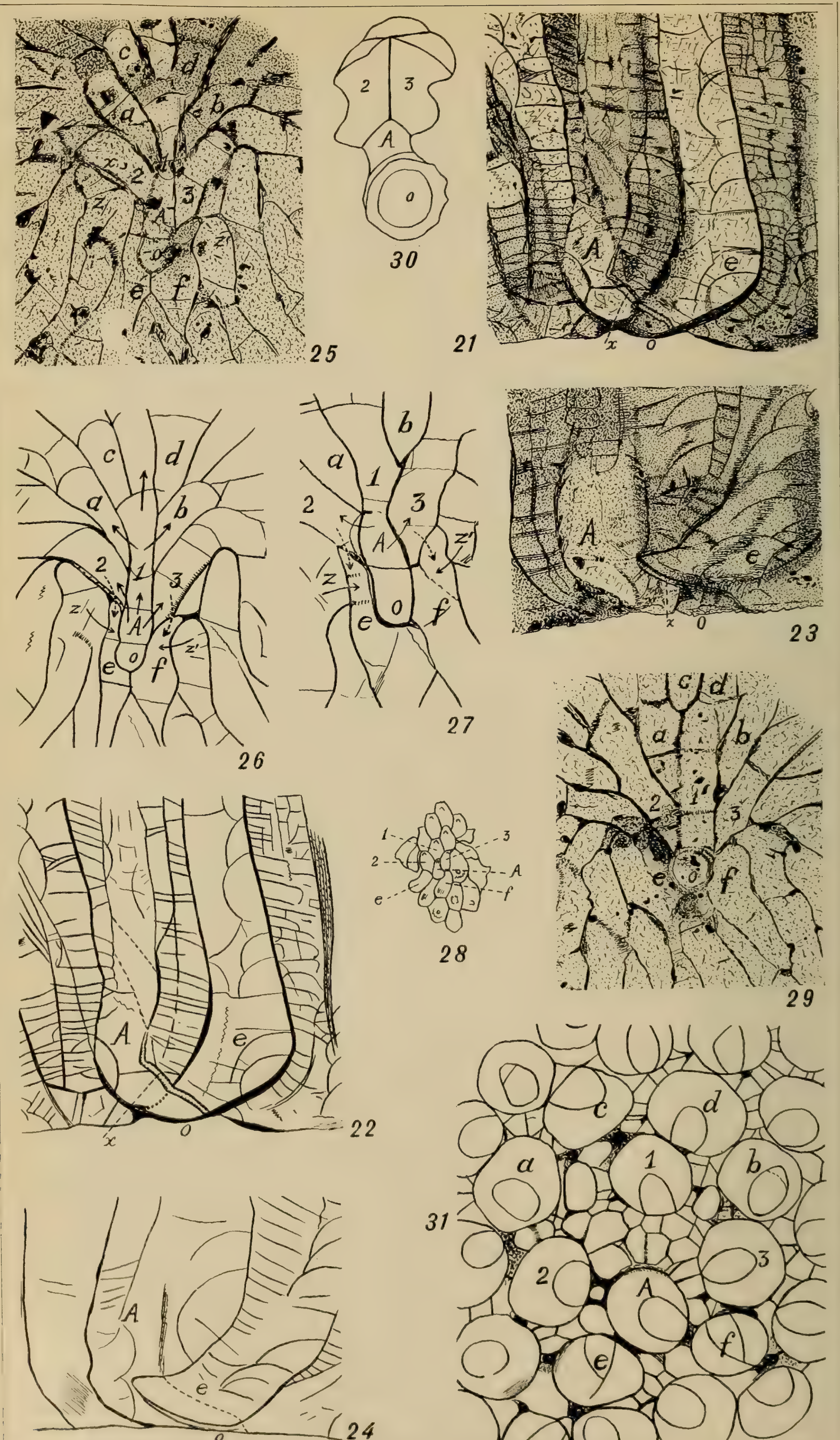
Showing the origin of the Fenestella-like rays. The section cuts at a higher level than figure 18. × 43. Phylloporina bed, Cannon Falls, Minnesota. (56-6.)

FIGURE 20.—*Vertical Section through the Ancestrula, etcetera, of Prasopora conoidea, with Lines m-m', etcetera.*

To show the level of various transverse sections. (Same specimen as figures 21, 22, and 35.) × 30.



DEVELOPMENT OF THE MONTICULIPOROIDS



DEVELOPMENT OF THE MONTICULIPOROIDS

PLATE 21.—DEVELOPMENT OF THE MONTICULIPOROIDS

FIGURE 21.—*Vertical Section through the initial Region of a Colony of Prasopora conoidea.*

Showing a portion of the protoecium and the ancestrula. Most of the protoecium has been weathered away (cf. figure 23). The bud *e* arises to one side of the ancestrula and not from the ancestrula. The peculiar thickened wall of the ancestrula is also well shown. × 43. Phylloporina bed, Cannon Falls, Minnesota. (104-14.)

FIGURE 22.—*Semi-diagrammatic Drawing from Figure 21.*

FIGURE 23.—*Vertical Section through the initial Region of another Specimen of Prasopora conoidea from the same Locality.*

The entire protoecium is shown in this specimen. Its perfectly circular outline (cf. figure 9) could be seen on the base of the colony before the section was cut. × 43. (106-14.)

FIGURE 24.—*A Section of the same Specimen as Figure 23.*

Made in a plane parallel with and slightly to one side of the latter section. This section shows how the bud *e* arises well to one side of and laps over the ancestrula and protoecium. Its tip is also elevated considerably above the substratum. × 43.

FIGURE 25.—*Transverse Section through the initial Region of Prasopora conoidea at the Level r-r′, Figure 20.*

Showing the protoecium, ancestrula, and primary buds. Note that the tip of the bud *f* is not in contact with the ancestrula. × 43. Phylloporina bed, Cannon Falls, Minnesota. (104-21.)

FIGURE 26.—*Semi-diagrammatic Drawing from Figure 25.*

FIGURE 27.—*Semi-diagrammatic Drawing of a similar Section of another Specimen of P. conoidea from the same Locality.*

In figures 26 and 27 the probable derivation of the buds is shown by the arrows. The broken arrows indicate an alternative interpretation of the derivation of the buds *e* and *f*. × 43. (104-16.)

FIGURE 28.—*Portion of a young Colony of the recent Bryozoan Membranipora, after Barrois.*

To show the identity of the budding pattern with that of the Trepostomata. × 7½.

FIGURE 29.—*Transverse Section through the initial Region of Phylloporina corticosa.*

Showing a beautifully preserved protoecium, ancestrula, and primary buds. Note the striking similarity to similar sections of *Prasopora*. × 43. Phylloporina bed, Cannon Falls, Minnesota. (56-7.)

FIGURE 30.—*Drawing of the recent Bryozoan Tubulipora, after Barrois.*

For comparison with figure 29 and figures 7 and 8. × 40.

FIGURE 31.—*Transverse Section through an Adult Colony of Prasopora conoidea at the Level m-m′, Figure 20.*

Same section as figure 32. × 43. Phylloporina bed, Cannon Falls, Minnesota. (104-24.)

PLATE 22.—DEVELOPMENT OF THE MONTICULIPOROIDS

FIGURE 32.—*Photograph of the same Section as Figure 31.*

The arrangement of the zooecia in the maculæ is the same as in the initial region. × 18.

FIGURE 33.—*Vertical Section through the initial Region of Prasopora conoidea, from Cannon Falls.*

Note the position of the tip of the lateral, posteriorly directed bud—in this section directed to the left. × 18. (106-3.)

FIGURE 34.—*Vertical Section through the initial Region of Prasopora conoidea.*

In a plane at right angles to that of figure 33 and figures 21, 22, etcetera. × 18. (106-9.)

FIGURE 35.—*Same Section as Figure 21. × 18.*

FIGURE 36.—*Same Section as Figure 25. × 18.*

FIGURE 37.—*Same Section as Figure 1. × 18.*

FIGURE 38.—*Same Section as Figure 16. × 18.*

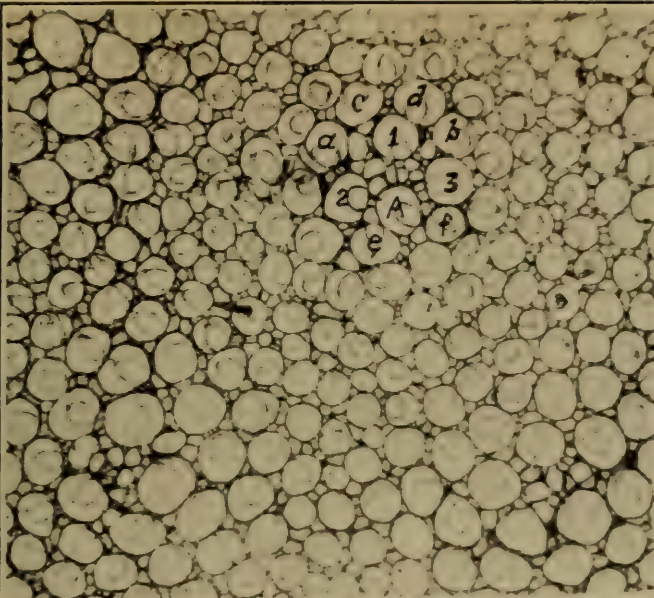
FIGURE 39.—*Same Section as Figure 7. × 28.*

FIGURE 40.—*Transverse Section of the initial Region of Rhombotrypa quadrata (Rom.), cutting a little above the Protoecium.*

Note the acanthopores. × 18. Cut No. XVI, Tanner's cr. Liberty formation. (106-22.)

FIGURE 41.—*Base of a Colony of the recent Bryozoan Discoporella.*

Note the great similarity of the budding plan to that of the Trepostomata. × 18.



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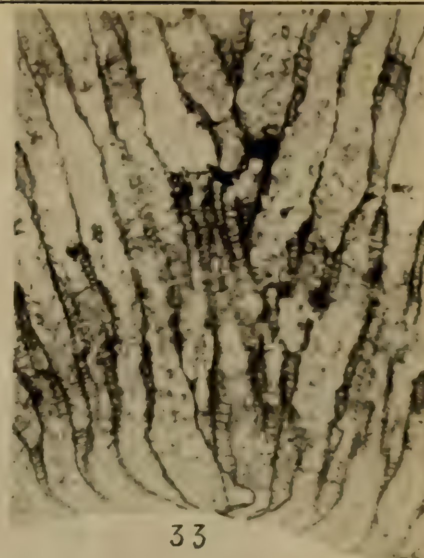
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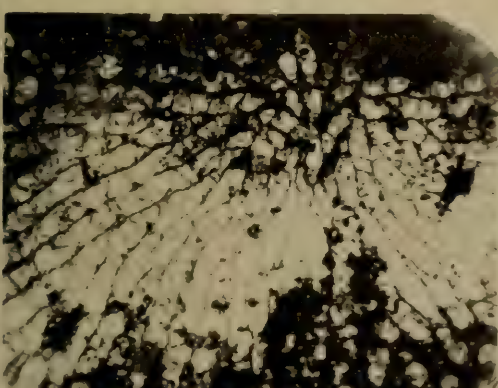
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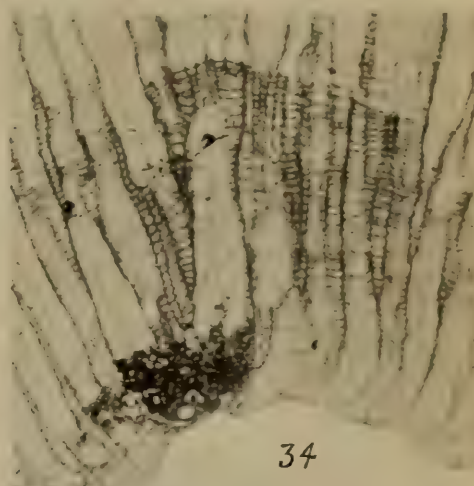
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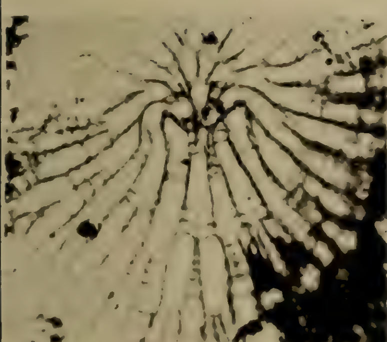
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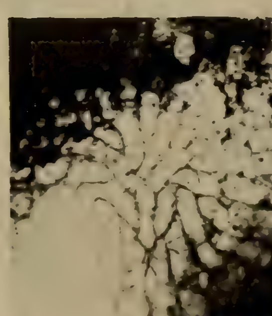
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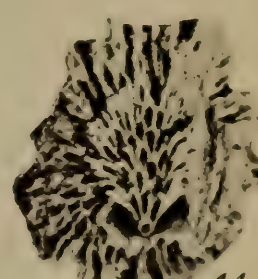
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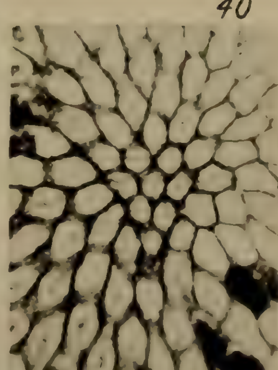
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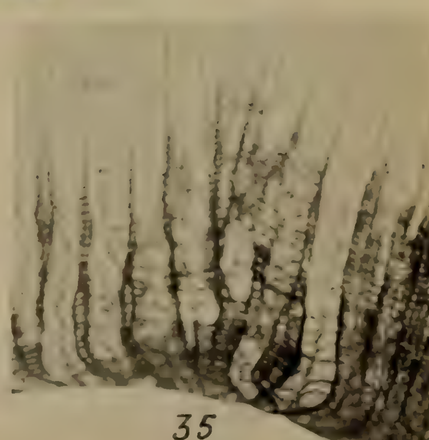
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DEVELOPMENT OF THE MONTICULIPOROIDS

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

ORISKANY SANDSTONE OF ONTARIO[1]

BY CLINTON R. STAUFFER

(*Presented before the Paleontological Society December 28, 1911*)

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Work and Conclusions of other Investigators

Few horizons in Ontario are of more geological interest than that of the Oriskany sandstone. This is largely because of its abundance of well preserved fossils and the relation which it bears to the preceding and succeeding formations. Apparently, on the authority of Billings, Logan gives a list of thirty species from the Oriskany sandstone[2] of North Cayuga township, in which ten are characteristic Oriskany forms, and the remainder are among those usually found in the Onondaga (Corniferous) limestone. About ten years later Nicholson writes, "The fauna of the Oriskany sandstone of Canada is, with very few exceptions, identical with that of the Corniferous (Onondaga) limestone. All the typical and characteristic forms of life in the former pass up into the latter, and it is thus impossible to draw any paleontological line of separation between them."[3] He says further, "I have myself detected no fossils in the so-called Oriskany sandstone which I have not also recog-

[1] Published by permission of R. W. Brock, Director of the Geological Survey of Canada.

Manuscript received by the Secretary of the Geological Society of America February 28, 1912.

[2] Sir William E. Logan: Geology of Canada, 1863, pp. 360-361.

[3] H. C. Nicholson: Paleontology of the Province of Ontario, 1874, p. 8.

nized in the overlying Corniferous (Onondaga) limestone."[4] Schuchert's list of Oriskany fossils, made up from Hall's collection, indicates a mingling of Oriskany and Onondaga fossils in the Ontario outcrops. Out of seventy-six species listed for the Oriskany of Canada, fifty-two are reported to pass from it into the Onondaga limestone.[5] Somewhat later, in referring to the above mentioned list, Schuchert says, "When this work was in hand it was apparent that there had been some mixing of Corniferous (Onondaga) corals with those of the Oriskany fauna and a number of species were then eliminated. It now appears that more of these corals must be removed from Professor Hall's Oriskany collection."[6] He then gives a revised list, dropping ten species, but still retaining forty-two as common to the two formations. It is interesting to note, as indicated by Whiteaves,[7] that most of the collection from the Ontario Oriskany, now in the museum of the Geological Survey at Ottawa, was made by Mr. John De Cew, a civil engineer and amateur geologist. It seems that Hall's collection, on which Schuchert's list was based, came from the same gentleman, and any one who has visited the field in question knows how easily a person might confuse his collections. While discussing the Oriskany and Onondaga faunas in their paper on "Paleozoic Seas and Barriers in Eastern North America," Ulrich and Schuchert state, "The Oriskanian invasion attained the last locality (near Cayuga, Ontario) about the same time that the Onondaga invasion, coming in from the southwest, arrived there, the result being that the Onondaga and late Oriskany faunas, originally very dissimilar in character, became one, making together what is now known as the eastern Onondaga fauna. The blending of these two different faunas (Oriskany and Onondaga) can be seen to best advantage in the townships of Oneida and North Cayuga, Ontario, where there is a sandstone filled with late Oriskany fossils. The sandstone rapidly passes into a sandy limestone and then into the typical Onondaga limestone. . . . Out of seventy-two species found here (in the Oriskany) not less than forty-two pass up from the lower horizon into the Onondaga."[8] Still later Weller writes, "The mingling of the Onondaga and Oriskany faunas in western Ontario . . . suggests that this was the first point of contact between the immigrant fauna (Onondaga) and the preexisting Oriskany."[9] Others might be quoted, but these statements are sufficient to

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[4] H. C. Nicholson: Idem, p. 8.
[5] Charles Schuchert: 8th Ann. Rept. N. Y. State Geologist, 1888 (1889), pp. 51-54.
[6] Charles Schuchert: Bull. Geol. Soc. Am., vol. xi, 1900, p. 324.
[7] J. F. Whiteaves: American Geologist, vol. xxiv, 1899, pp. 228, 229.
[8] E. O. Ulrich and Charles Schuchert: N. Y. State Museum Bull. 52 (Pal. 6), 1901 (1902), pp. 652-653.
[9] Stuart Weller: Journal of Geology, vol. xvii, 1909, p. 261.

make it evident that there is a rather general impression that the Onondaga and Oriskany faunas are mingled in the deposits of the region mentioned above. Hence some of the results of work recently done in that vicinity may be of interest.

The Exposures in Haldimand County, Ontario

Sandstone of North Cayuga Township

In Ontario the Oriskany sandstone is represented in Welland and Haldimand counties (the two counties lying along the north shore of Lake Erie immediately to the west of Buffalo) by remnants of a much more extensive formation. The largest and most important of these remnants lies under a very thin mantle of drift and covers a considerable portion of several square miles just west of Decewsville, in North Cayuga township, Haldimand County. The center of the area thus designated is the location of the De Cew quarry of former days, but the sandstone has been taken out at more than a dozen localities and, on a small scale, is now quarried at three or four places. At the Oneida Lime Company's quarry, 2 miles west of Decewsville, the Oriskany is composed of 20 feet of coarse grained friable white to yellowish sandstone. At some horizons, especially in the upper part, there occur occasional concretion-like bodies of sand which have been cemented into masses resembling quartzite. This sandstone lies unconformably on a weathered buff to yellowish brown, somewhat porous, magnesian limestone of Silurian age, and the lowest layers often contain subangular fragments of the underlying formation, while at other places the sand has penetrated the cracks and crevices of the Silurian and now appears as thin veinlike seams cutting the rock in all directions or filling pocket-like holes in it. The thickness of the sandstone varies much from place to place, owing to the marked unevenness of the surface on which it lies. The Oriskany is overlaid unconformably by about 4 feet of arenaceous chert and cherty limestone. These upper beds often contain a considerable amount of sand, which sometimes gives them the appearance of mortar beds. Good sized pieces of the sandstone, containing characteristic Oriskany fossils, may be found embedded in the lower part of the cherty limestone, while at other places not far distant the Onondaga rests directly on the Silurian, with only here and there remnants of the Oriskany lying between.

Fossils from North Cayuga Township

The coarse sandstone carries an abundance of such forms as *Spirifer arenosus* (Conrad), *Spirifer murchisoni* (Castelnau), *Eatonia peculiaris*

(Conrad), *Rhipidomella musculosa* Hall, *Hipparionyx proximus* Vanuxem, *Meristella lata* Hall, *Leptostrophia magnifica* Hall, *Leptostrophia magniventra* Hall, *Rensselœria ovoides* (Eaton), *Rensselœria cayuga* Hall and Clarke, *Platyceras nodosum* Conrad, *Platystoma ventricosa* Conrad, etcetera. In fact about all of the most characteristic forms of the central and western New York Oriskany occur here.

During the course of a half dozen or more days collecting at this place, some of the time with the assistance of Mr. Walter A. Bell, a fair collection from all beds was made. A single specimen of *Strophonella ampla* was found occurring in such relation to *Spirifer arenosus* as to make it seem probable that the two species lived at the same time. However, since this find was made at or very near the top of the sandstone, it may not be significant of anything. Then, too, it is to be remembered that *Spirifer arenosus* has been found in the Onondaga limestone and *Strophonella ampla* at least as low down as the Schoharie grit. In the sandstone there was also found a coral belonging to the genus *Favosites* and resembling quite closely *Favosites turbinata* of the Onondaga limestone. A study of this form, however, has made it seem more than probable that it is a different species. The arenaceous chert and cherty limestone overlying the sandstone carry a pure Onondaga fauna with not a single species, other than long range forms, properly belonging in the Oriskany. It is true that many specimens of Onondaga fossils can be obtained from rock which is more sandstone than limestone, but in every case where these have been obtained in place they have been found to occur above the Oriskany and never mingled with that fauna.

SANDSTONE OF WALPOLE TOWNSHIP

Ten miles farther west, near the village of Springvale, Walpole township, there is another outcrop of sandstone resembling very closely that just discussed. It occurs as a narrow surface outcrop, extending for a distance of several miles, and consists of about 8 feet of coarse white to yellowish sandstone, with hard white masses resembling quartzite, as at the previous locality. This sandstone usually rests on several feet of cherty material, which at places where the base is exposed is found to rest unconformably on the Silurian limestone. This latter shows the sand penetrating cracks, etcetera, as previously mentioned—that is, the base of the Devonian and the horizon of the true Oriskany sandstone apparently lies below the chert. The sandstone near Springvale is overlaid by arenaceous chert and cherty limestone, which appear to be the same, both lithologically and faunally, as those beds overlying the Oriskany sandstone 10 miles farther to the east. One difference, however,

deserves mention. No evidence of unconformity was discovered at the top of this sandstone, and certainly there are no masses of sandstone included in the limestone, although much sand is mingled with the calcareous sediments for 2 or 3 feet above the true sandstone.

FOSSILS FROM WALPOLE TOWNSHIP

Among the common fossils of this sandstone are *Centronella glansfagea* Hall, *Spirifer divaricatus* Hall, *Meristella nasuta* (Conrad), *Amphigenia elongata* (Vanuxem), *Pentamerella arata* (Conrad), *Reticularia fimbriata* (Conrad), *Pholidostrophia iowaensis* (Owen), *Spirifer macrothyris* Hall, *Spirifer duodenarius* (Hall), *Zaphrentis gigantea* Lesueur, *Michelinia convexa* d'Orbigny, *Zaphrentis prolifica* Billings, *Favosites turbinatus* Billings, etcetera. This fauna is truly that of the Onondaga limestone and in it was found none of the characteristic Oriskany species.

WELL RECORDS

Well records at Hagersville, about half way between the two localities under discussion, give no evidence of sandstone at the base of the Onondaga, although some of the wells to the southwest do strike sandstone at this horizon, while others do not. These outcrops of sandstone are, therefore, not continuous and lie at different horizons, as their faunas and stratigraphic relations show. Moreover, a mingling of the Oriskany and Onondaga faunas at this locality does not exist. What seems to have happened is that the Oriskany Sea withdrew entirely from Ontario and that a land interval followed it. With the transgression of the Onondaga Sea the Oriskany sandstone suffered severely from erosion, and the arenaceous materials thus obtained were incorporated into the lower layers of the Onondaga limestone. Locally, as at Springvale, this sand was of sufficient quantity to form considerable beds of sandstone. The subsequent changes which have increased the similarity of the two deposits, namely, the formation of the quartzite-like masses, have probably been brought about at a much later date.

Conclusions

Near Syracuse, Onondaga County, New York, there are numerous outcrops of the Onondaga limestone and of the Oriskany sandstone. At some of these places the basal portion of the Onondaga contains a considerable amount of sand. The outcrop in the gorge just west of Manlius shows a stratum between 2 and 3 feet in thickness, in the lower part of which "the sand predominates over the lime, but toward the top the lime

increases at the expense of the sand and gradually the top of the stratum becomes entirely lime." [10] This stratum of sandstone and arenaceous material carries an Onondaga fauna and forms the basal layers of that formation. It rests directly on a sandstone which contains the characteristic Oriskany fossils. The stratigraphical evidences of unconformity in this case are apparently wanting, but the Paleontological evidences are rather marked. And thus it appears that the conditions which prevailed in Ontario during early Middle Devonian were identical with those which existed in portions of New York at the same time, and the "Decewsville formation," [11] in which the mingled Oriskany and Onondaga fauna has been supposed to occur, is not an independent unit.

[10] C. J. Hares: Letter of February 9, 1912.

[11] E. O. Ulrich and Charles Schuchert: Loc. cit., p. 653.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

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CRITERIA FOR THE RECOGNITION OF ANCIENT DELTA DEPOSITS

BY JOSEPH BARRELL [1]

(*Presented before the Society December 29, 1911*)

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[1] Manuscript received by the Secretary of the Society January 10, 1912.

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Introduction

On the earth's surface, ranging from mountain crests to oceanic deeps, are wide gradations in geologic process and organic environment, but the line which most sharply draws division between two worlds of process and of life is the strand. In the study of the sediments, holding as they

do the record of earth history and organic evolution, a fundamental question is therefore whether the strata were laid down in contact with the air or beneath the level of the sea. If fossils are present they commonly give an answer, but the absence of fossils from many formations leaves the problems of origin to be solved by other methods of attack. It is important that the criteria which are used for such purposes should be always subject to scrutiny in order that inherited errors may be detected and further progress made toward refinements of discrimination—refinements which though concerning small details may yet result in a disproportionately large increase of knowledge in the interpretation of the sediments. It is in delta deposits especially that the line of the ancient strand is difficult to draw, since it is not here coincident with the limits between erosion and sedimentation and the same formation is made in part above, in part below the level of permanent water. It is the purpose of this paper, therefore, to review the validity of the criteria which have been employed to discriminate between terrestrial and subaqueous sediments—criteria whose use is preliminary to a knowledge of the physiography or climate of those former periods where knowledge is drawn from the stratigraphic record; since building on an insecure foundation results in danger to the whole superstructure of knowledge.

But before a discussion of such criteria is given it is important that the view should be accepted that at certain geologic times deltas may have been of widely different character and have varied greatly in importance from the rather limited place which they now hold in the physiography of the lands. The field of progress in science is hedged in by the limits of the mental angle of vision, and the range of hypotheses should therefore be made broad before examining in detail the possibilities of a problem. The rise of geology as a science depended on the establishment of the principle of uniformitarianism—that the present is the key to the past. But applied too rigidly it narrows the visual angle, since the scale or rate at which various processes work may vary greatly in successive periods and their changing dominance is now believed to have resulted at times in great climatic and geographic contrasts. The highly variable importance of glaciation in geologic history may be used as an illustration of a similarly possible wide variation from period to period in delta-building. No *a priori* limit can therefore be set safely to the maximum area and thickness which under favoring conditions deltas may attain. In fact, as the successive geologic periods differ from one another in character, it should follow that the importance of delta-building will vary from age to age according to the physiographic stage-setting of the continents. A direct application of the growth of glacial

theory during the past half century may be made to the problem of the relation of continental and marine deposits. The rise of geology in western Europe, where mountain glaciers and river deltas though interesting are relatively small and inconsequential factors at the present geologic time, and where marine erosion on the other hand is an impressive phenomenon, gave an initial trend to geology which underestimated the possibilities of continental glaciation and continental sedimentation. A truer perspective regarding glaciation has been attained by the study of the polar regions and of sedimentation by the study of other continents; but the records of delta deposits and their distinction from other forms of sedimentation are not so clear as are the marks of glaciation, with the result that the criteria for the recognition of delta deposits are still open to discussion and further elaboration.

But glaciers have their cycle of inception, growth, and retreat, and in any refined application of the criteria of glaciation they must be discussed from the standpoint not only of the part of the glacier which is concerned but of the stage in the glacial life. The erosion by rivers likewise passes through its cycle of youth, maturity, and age, and the characteristics of the river valley and river waste change with the distance from the headwaters and with the progress of the erosion cycle. There must also be a delta cycle, and it is to be expected that the size of the delta and the character of its deposits will depend not only on the original relation of the other physiographic elements of the continent, but on the progress of the cycle of erosion on the one hand and of the cycle of deposition on the other.

Consequently the first part of this paper is largely deductive in its mode of presentation and deals with the definitions of a delta and its parts, followed by an analysis of the delta cycle, dependent on river erosion and the changing level of the sea. The conception which it gives is then applied to a certain sequence of formations as an example of its use and tends to ascribe to delta-building a kind of deposition which has heretofore been assigned to an estuarine origin.

The second part of the paper is inductive in its method, and consists of a review of all those stratigraphic criteria which have been used within recent years as evidence by which to separate continental and marine formations. Some are concluded to be of negative value; others may indicate either mode of origin, according to their character and dominance. Still others are positive criteria for the parts of the formations in which they occur. Although the method is inductive, yet in the absence of observed facts in regard to some modern conditions of sedi-

mentation, deduction from known principles of action is needed to supplement the conclusions from partial observations.

Part I.—Larger Relations of Deltas

DEFINITIONS OF A DELTA AND ITS PARTS

Essential features of a delta.—A delta may be defined as a deposit partly subaerial built by a river into or against a body of permanent water. The outer and lower parts are necessarily constructed below the water level, but its upper and inner surface must be land maintained or reclaimed by river building from the sea. A delta, therefore, consists of a combination of terrestrial and marine, or at least lacustrine strata, and differs from other modes of sedimentation in this respect. Its place in a classification of modes of origin may be given as follows:

All sedimentation is continental, littoral, or marine. Continental sedimentation may be in turn subdivided into terrestrial, paludal, and lacustrine; terrestrial formations comprising deposits made by wind, rain wash, rivers, or land ice; lacustrine including fresh-water and salt-water lakes. Paludal sediments form a transitional type between terrestrial and lacustrine, but in the playas of desert basins and the swamps of deltas they are quite distinct in character and in life content also from either the more or less permanent lakes on the one hand, or, on the other, the river plains which are only temporarily flooded. Marine sediments are either of terrigenous or pelagic origin. It is with the division of terrigenous sediments—sediments directly born of the land and restricted to within a few hundred miles of shore—with which we have here to deal. They are deposited over a wide range of conditions, in the open sea or in partly landlocked bodies of water, at abyssal depths and on shallow bottoms lighted by the sun, agitated by the waves. In bays and estuaries gradations toward fresh-water conditions may occur, but the littoral, that zone alternately covered and laid bare by tides, separates the waters of the oceans from those of the lands. The distinction between the waters is drawn geologically by means of the faunas, but from the structural standpoint no such line can be drawn between the deposits of lakes and those of shallow seas. Sedimentation with its record of earth history may take place under all these environments, but delta deposits alone cross the shore. The presence of a strand zone within the formation is the distinctive feature, and in this paper, therefore, delta deposits will be spoken of as terrestrial and subaqueous, and the conditions of deltas built into continental waters will not be discriminated from those built into the marginal waters of the oceans. The

blanket of sediments which extends across the shore may pass outward into deposits of the open sea and must be classified into zones according to the changing conditions of deposition. All those zones which contribute to the building of a delta are parts of it as a complex physiographic structure. Those which do not aid in the outward or upward growth of the delta should be ruled out of its membership. For greater clearness of view a table is given showing a classification of sedimentary deposits and those divisions which may contribute to delta growth.

Classification of Sedimentary Deposits

SUBDIVISIONS			DEPOSITS OF MIXED CONTINENTAL AND MARINE FORMATIONS (DELTAS FACING SEAS)
Continental (Above tidal reach)	Terrestrial	Glacial Eolian Pluvial Fluvial	*Subaerial topset beds* (mostly fluvial)
	Paludal	Intermittent Perennial	
	Lacustrine (fresh and salt)	Shore Bottom	(The littoral and fluvial zones are not sharply separated in deltas.)
Littoral (Between tidal limits)	Tidal marsh Lagoon Beach		
Marine (Below tidal limits)	Terrigenous	Offshore (Breaking waves, undertow)	*The shore face* (Steeper slope produced by wave action)
		Estuarine or bay (Brackish water)	*Subaqueous topset beds* (Gently sloping surface produced by wave action)
		Shallow sea (Epicontinental sea)	*Foreset beds* (Steeper slopes below wave base)
		Oceanic (Also Mediterranean)	*Bottomset beds* (Flat distal slopes below wave base)
	Pelagic	Epicontinental limestones Oozes Abyssal red clay	

The dominance of river action over the opposing sea is expressed by a broad but irregular convexity of shoreline, though confluent deltas may give rise to an extended coastal plain of fluviatile origin and conform to the regional trend of the shore, either concave or convex toward the sea. A delta is typically built in front of a river valley, not within its walls. A drowned valley, however, is reclaimed by the river readvancing into it

under temporary delta conditions. A basin is a structural depression surrounded by uplands, and if rivers maintain a land surface, notwithstanding subsidence, then deltas do not result. If, however, a rapid subsidence gives temporary lacustrine conditions the rivers work to reclaim the land, partly by supplying sediment to the lake bottoms, more largely by building out deltas into the lake, but on the margins of the basin the deposits differ in no respect from those accumulated under purely fluviatile conditions. If subsidence is progressive the rivers build upward, but deltas exist only in so far as the rivers keep flowing into bodies of permanent water.

From the shore front the river-built plains may extend landward many hundred miles, as seen at present on the great delta plain of China. In the other direction may extend a still wider reach of sea. The determination of ancient delta conditions from the study of the strata requires, therefore, the demonstration of evidence that both subaerial and subaqueous sediments were deposited. The nature of each part may not, however, be different from that of formations which were wholly subaerial on the one hand or subaqueous on the other, so that a broad study of the formations will commonly be necessary to prove the synchronous and contiguous development of both kinds of strata and hence the existence of deltas.

Deltas indicate a somewhat balanced contest between the constructive rivers and the opposing lake or sea, but the relative aspects are continually changing; deltas if now building rapidly outward show by that fact that but recently subsidence brought the sea inland. The problem of the shifting conditions through time as recorded by successive strata is therefore much more complicated than the study of the surface of the existing stage.

The factors in delta construction and destruction.—Rivers excavate their channels and undermine their banks during times of flood, and although in this manner they act locally as degrading agents and contribute to the sea rather than to the land, yet the delivery of this material to the offshore sea bottom builds it up and weakens the effect of the waves on the coast. Indirectly, therefore, erosive work of the channel waters advances the work of delta-building. The overflow waters, on the other hand, deposit a large proportion of their waste on the floodplain and directly build it upward and outward. With the draining away of the flood waters the work of aggradation is shifted to the channel, the excess of sediment diminishing its cross-section and maintaining the velocity of the current until the latter is able to carry through the balance of its much diminished load.

Strong tides scour the lower channels, keeping them large and open. But the inrushing tide has greater carrying power than the ebb unless the latter is assisted by a strong river current. Consequently, although there is great channel scour, sedimentation is all the more rapid in the two zones of slack water, that of the salt marshes on the one hand and the adjacent shallow sea bottom on the other, and the greater strength of the flood tide tends to keep even the marine sediment near the land. The carrying of material in suspension until deep water is reached prevents to that degree the building of deltas. But the silt deposited over the salt marshes at full tide tends on the other hand to build rapidly upward the floodplain to the level of high tide, so that tides serve in this respect to extend the subaerial plain. If the river empties into a shallow sea the sediment which is dropped from suspension where the tidal current weakens will commonly be within the reach of the waves and the deposit, like that from the river currents proper, diminishes the shore action of the waves, thus doing indirectly its part toward extending the delta. The strength of the tidal action in itself does not therefore control ultimately the presence or absence of deltas, though the contrary view is commonly expressed in text books, based on observations on the scouring power of tides in estuaries. The Indus delta, for example, is built in the presence of a tidal range of 10 feet and that of the Ganges against a tide of 16 feet.

Waves are the more real destroyers of the delta front. They plane back the shore, and by keeping the finer material in suspension it is swept out to deeper water. If it were swept radially out from the land, and if the limiting depth of wave action were soon reached, the effect would be chiefly to build outward the subaqueous platform of the delta at the expense of the subaerial plain, thus modifying the form but not destroying the individuality of the delta. But the lateral component of wave action works the material along shore for indefinite distances. Currents parallel to the shore aid in the dispersion and, cooperating with strong wave action over a shallow sea—as, for example, in the North Sea—the sediment may be widely distributed both along shore and away from the land. Thus wave action aided by lateral currents, either of tidal or non-tidal origin, tends to destroy the delta by redistribution of its material. The waves work most strongly against the shore, and by piling up beaches and by excavating the foreshore serve to differentiate more sharply the subaerial and submarine portions of the delta.

From this brief statement of the parts played by the several factors in delta construction and destruction it is seen that the two directly opposing processes are, first, those of floodplain aggradation, building the land

upward and outward, giving convexity and unity to the delta; and, second, marine planation, carrying the sea inward and downward and tending to maintain the straightness of the shoreline. River and tidal currents greatly modify the outline of the delta and the place of growth, but do not control the existence of the subaerial and subaqueous plains. Delta-building is thus due to a dominance of fluvial over marine action.

The bottomset beds.—A delta consists typically of several parts, as shown in figures 3 and 4, pages 396 and 399, and are more or less distinctly unlike in nature. The outermost deposits consist of materials which have settled slowly from suspension in water, making an extended mantle of gradually diminishing thickness. These are the bottomset beds, and do not differ in any easily recognizable way from those deposits of similar depth where waves and currents have prevented the formation of a delta. Stratigraphically they are, therefore, not to be discriminated, and the demonstration of deltaic conditions must rest on other lines of evidence.

The foreset beds.—Nearer shore is the steeper delta face or foreset slope, made by the accumulation of that coarser material swept outward by currents and waves until the depth of wave base is reached, the carrying power disappears, the material finally settles, and being built out at the top tends to develop the front at a relatively steep angle. Where the sediment is dominantly coarse and but little of it carried in suspension, the steepness of the foreset slope approaches the angle of repose. But where, as is the case with large rivers, the detritus is mostly fine in texture the foreset beds are built largely by material settling from suspension. Both in slope and texture there is less distinction from the other parts of the delta, the foreset beds grading especially into the bottomset beds, the greater steepness being due to the greater rapidity of settling near the limit of wave action.

The topset beds—Subaqueous plain.—The inner part of the delta consists of the topset beds, whose upper surface slopes gently seaward at such a grade as is necessary to convey that detritus which is swept along the bottom to the edge of the foreset slope. The topset surface consists of two distinct portions, the subaqueous and subaerial plains, separated by a narrower transition belt—the shore face and littoral zone. The subaqueous plane is the outer part permanently beneath the water level. Across it material is transported by wave action and currents of the open water. It is characterized by being the home of marine organisms, affected by waves rather than currents, and never exposed to the air.

The shore face and littoral zone.—The shore face is the relatively narrow slope developed by the breaking waves, a slope which separates

the subaerial plain above from the subaqueous below. Vigorous wave action develops a pronounced shore face and separates more sharply the two parts of the topset surface, but in protected situations it may cease to be a distinct feature of the delta. The shore face is geologically a line of greatest importance, yet it is seen to be in places a somewhat indefinite demarcation, the beds deposited on the two sides of the strandline showing approaches toward each other. This is especially true of lagoons within the subaerial plain and of islands thrown up by the waves on the surface of the subaqueous plain. On small deltas of coarse material built into lakes, with weak wave power, the shore face is practically coincident with the upper edge of the foreset slope and the distinctions between the two parts of the topset plain are not emphasized. It is such small deltas, however, which are commonly used as text-book illustrations of delta structure. But in the large deltas—for example, in that of the Mississippi—broad areas are covered with shallow water, and consist structurally of topset beds as closely allied with the land surface as with the deep-water portions of the delta. From the standpoint of living things, however, the shore face dividing the topset beds into two parts is the zone of fundamental importance, the strand which separates the two worlds of life—the regions of continental and marine sedimentation.

The littoral zone is that belt of shore alternately covered and laid bare by tides, or where these are insignificant in range, by the effects of powerful onshore or offshore winds. Special faunas and floras dwell in this narrow belt adapted to alternate exposure to air and salt water. For that reason the definition of the littoral should be restricted to the vertical limits affected by the maximum range of the water level as recurring once or twice per month and not extended as an indefinite term to include what may be near the shore, yet belongs wholly either to the sea or land. The steepness of the outer shore face causes the littoral to be there a narrow belt subject to wave action. It attains a greater breadth in the lagoons and salt marshes which lie behind the beach, and reaches a maximum development under the flat and swampy condition attending delta growth. Here there may be all gradations into fresh-water swamps of the subaerial plain, but, as shown in previous studies, the breadth of the littoral zone does not increase proportionately with the tidal range and occupies normally but a small part of the entire delta surface.[2]

Subaerial plain.—The inner parts of the delta are covered alternately by air and river water. The carrying agents comprise channel currents

[2] Barrell: Relative geological importance of continental, littoral, and marine sedimentation. Journal of Geology, vol. xiv, 1906, pp. 443-446.

and broad flood waters, and in arid or semi-arid climates the wind may take its part, but the direction in which it moves the waste is not determined by that slope which governs the movement of water. It is the subaerial plain which in popular thought constitutes the delta, but it is seen that in the process of delta-building it is but one facet of the larger surface of construction which reaches from the upper valley to the bottom of the water body. The outer parts of the subaerial plain of larger deltas are broadly flooded at longer or shorter intervals either from the river or the sea, but the distinguishing feature is that the surface is periodically exposed to the air, and marks of such exposure may be recorded in the accumulating sediments. Lacustrine and lagoon deposits, ranging from fresh to salt water conditions, are also intercalated, but the life of the plain as a whole is more of the land than of the sea.

The word delta is taken to refer more especially to the low-lying and projecting portion of the river deposit, but this grades with no line of demarcation into the materials of the river plain, which may reach farther inland. In ancient formations all parts of a fluviatile deposit which lie beyond the walls of the valley and face a body of permanent water must be regarded as essentially parts of a delta. From this standpoint the delta plain of China reaches westward more than 300 miles, and the deltas of the Ganges and Indus can not be set apart, so far as their strata are concerned, from the Indo-Gangetic floodplain, which completely separates the peninsula of India from the Himalayan mountain system.

The Nile and Rhine deltas as examples.—In order to give a proportionate view of the several parts of deltas as seen in actual examples, drawings are given of, first, the delta of the Nile, and, second, the combined deltas of the Rhine and Meuse and that of the Ems. In both examples the shore face is pronounced; strong wave action developing well marked barrier beaches, behind which are shallow lagoons dotted with islands and muddy flats. On the Nile delta the shore face extends to a depth of 6 to 10 meters or thereabouts, as shown by the closeness of the 6-meter contour to the land and the considerable distance of the 20-meter contour, not shown on the map. The 50-meter contour averages about 50 kilometers from shore and is especially developed on the east side of the delta, since this is the direction in which the dominant waves and currents carry the bottom material. The slope of the subaqueous plain is seen to be less than one in a thousand. From 50 to 200 meters in a transition zone to the foreset slope, 50 kilometers wide in front of the delta, but much narrower on the sides. Below 200 meters waves have no effect, and in a width of 30 kilometers there is a rapid descent to 1,000 meters depth. This, then, is the foreset slope. It is seen to

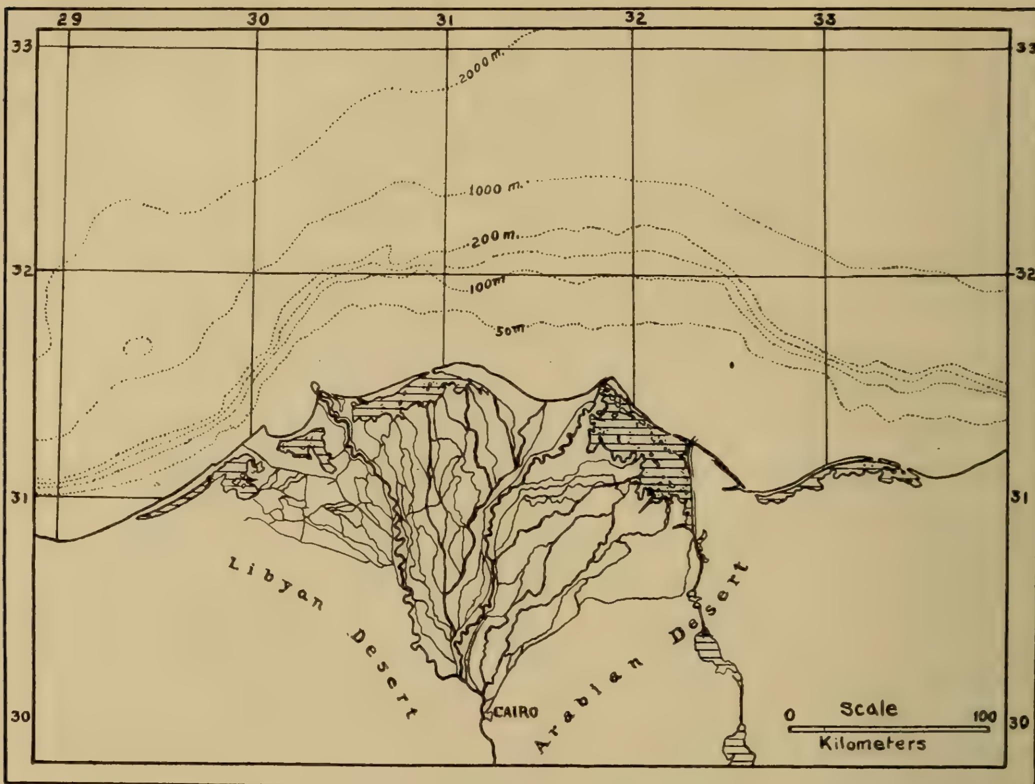

FIGURE 1.—*The Delta of the Nile*

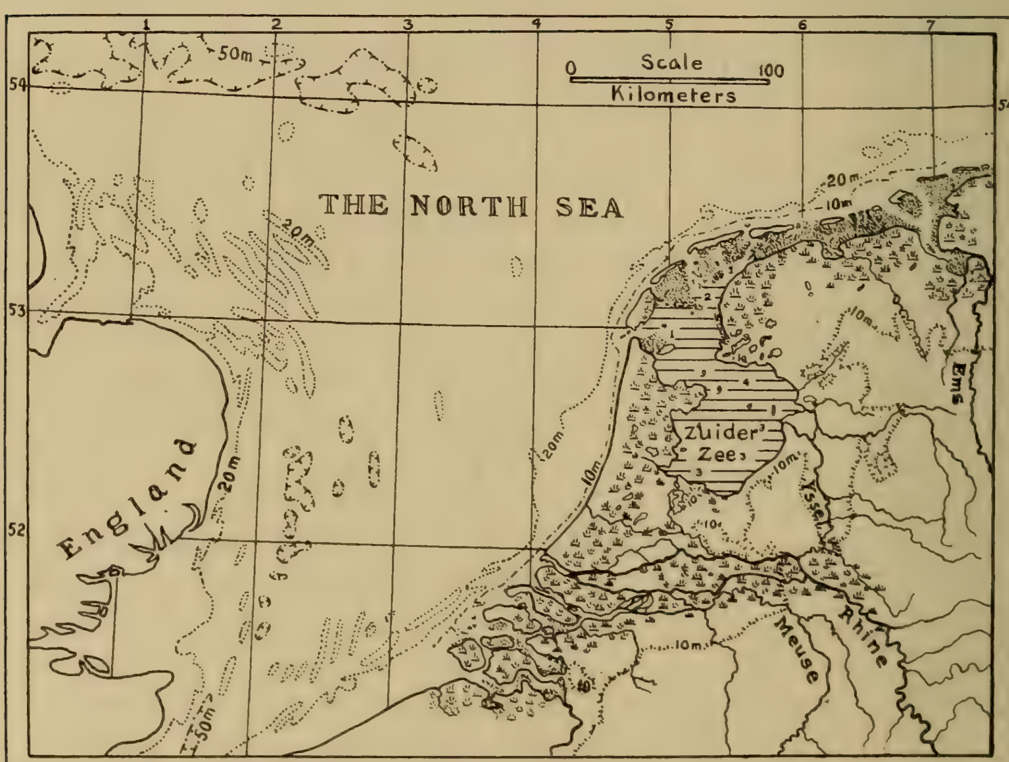

FIGURE 2.—*The confluent Delta of the Netherlands*

have a grade of about 26 per 1,000, a slope of 1 degree 30 minutes; steep in comparison with the other parts of the delta, but flat in comparison with angles generated by material rolling or sliding down a slope. Below the foreset slope and mainly to the eastward is a wide bottom, much flatter, and constituting the bottomset beds of the delta, between 1,000 and 2,000 meters deep. The convexity of the contours about the shore face down to 1,000 meters shows that these under-water parts are really a construction from the river-borne detritus and not the original profile of the Mediterranean basin. The Nile delta has not only given to modern tongues the word delta as a generic name, but all its parts are seen to be displayed in regular development, as befits a genotype. In the Netherlands, on the contrary, a confluent delta fringe has been built facing the North Sea by several rivers. The heavy northwest storms have constructed a strong shore face, behind which is a broad band of tidal flats and lagoons. The latter have been in part developed by a movement of subsidence pronounced during the past 800 years. The war of the inhabitants against the North Sea has prevented the inroads which the ocean might otherwise have made as a result of the subsidence, but has also banished a large part of the lagoons and swamps which would naturally mark the country. Outside of the guarding reefs the shore face descends to a depth of 10 and in places to 20 meters, beyond which a broad subaqueous plain stretches out and forms the bottom of the North Sea, the 50-meter contour lying 300 kilometers distant from the shore except over limited areas which are subject to excessive scour. Over this bottom the sediment is moved chiefly by wave action; it does not settle quietly from suspension, and the delta of the Netherlands can not be said to have either foreset or bottomset beds. Although the subsidence which has brought the North Sea into existence is known to be geologically recent, the land and bottom profiles show that sedimentation has already brought the subaerial and subaqueous plains into normal relation to each other. Erosion although dominant against the British coast can have had but minor effect in the vicinity of the Netherlands.

VARIATIONS AND BLENDING IN THE COMPONENT PARTS OF DELTAS

The relative importance of the several components of a delta varies in different examples within wide limits. First, fine waste and strong ocean currents result in an extended development of the bottomset beds; second, deep quiet waters of constant level permit a large proportion of the waste to accumulate as foreset beds; third, strong wave action, breadth of delta front, fineness of waste, and crustal subsidence favor the development of a wide subaqueous plain; fourth, weak waves, coarse and abundant sedi-

ment, separate rivers converging toward a shallow sea, and stationary crust favor great breadth of subaerial deposits.

Deltas may, furthermore, vary from miniature examples built into small lakes to deltas of subcontinental size. It is, consequently, misleading to discuss delta structure and delta growth chiefly from the easily studied small examples, with but brief mention of the larger deltas. In the interpretation of ancient delta deposits a similar or perhaps greater range in variations of structure must be anticipated, but that departure from present conditions which was most common was in the direction of shallow interior seas, whose bottoms for indefinite distances were nearly level and worked on by the waves. This physiographic setting eliminates the presence of bottomset and foreset beds, the clastic material of the subaqueous plain growing progressively finer in texture and smaller in quantity with distance from shore. Under such conditions the waves may spend their force on the bottom before reaching the shore, and the shallow sea fades out into shallow brackish lagoons and the fresh-water lakes, swamps, and playas of the river plain. Thus even the dividing line between the subaerial and subaqueous plains may become impossible to delineate and the deposits of a river floodplain grade through a delta into the contrasted deposits of an open shallow sea.

Widespread limestone deposits, thinning out gradually against the lands, imply high sealevels and low surrounding lands of such small relief as not to supply much clastic material to the water. Under such conditions, also, the sea must have shallowed out indefinitely, the waves spending their force on the bottom rather than the shore. If, however, as during the formation of the coal measures of the Pennsylvanian, erosion was vigorous on the land, then alluvial deposits must have replaced large parts of the sea. But on indefinite outward growth the deltas must have been developed over wide areas at such a low gradient as to result in stagnant drainage. The Yangtse River, for example, at the present time is said to have a fall of but an inch per mile for 200 miles from its mouth. Under such conditions large areas, shifting from time to time and corresponding on a larger scale to the border swamps of existing deltas, would be covered with permanent river water, giving rise to associated lacustrine conditions. During the time of river overflow the floodplain may be viewed as a temporary lake, with a sea instead of a land boundary on its outer side. With such flat gradients, shallow offshore waters, and consequent weak wave action, the shiftings of the shoreline will be more largely controlled by crustal movement and river-building than by marine action, and the horizontal movements of the strand through each succeeding stage will be at a maximum.

Under present physiographic attitudes of high continental relief the marine, lacustrine, and fluviatile phases are abnormally sharpened. Under the physiographic states of low relief, which have been more usual through geologic time, this sharpness of separation is seen to have been absent. This blending together of unlike parts in connection with a tendency to interpret sedimentary formations as marine or lacustrine has permitted an unjustified assignment of certain delta deposits to other modes of origin, with the result that the idea of delta formations is almost absent from the interpretation of the stratigraphic record. In approaching the subject of the criteria of ancient delta deposits, it is therefore to be held in mind that the several parts of a delta may vary in importance; they may vanish, or they may become blended into each other and lose their individuality. Nevertheless, the distinction of parts in the ideal delta is a necessary analytical step and serves as a basis for discussing the application of criteria.

At the beginning of this section a delta was defined as a formation built by rivers against a permanent body of water and maintained partly as a land surface. The discussion has served to show the great variety of conditions under which this may take place and the non-essential character of certain features which have been regarded not uncommonly as essential marks of deltas. This is especially true of the foreset beds, which assume great dominance and marked steepness in the case of small deltas built by torrential streams into deep lakes. From Gilbert's classic studies of deltas of this type[3] and the common occurrence of similar dissected deltas connected with Pleistocene glaciation, this particular variety of delta has become commonly accepted as the standard type, and the specific criteria by which it is identified have been unwarrantably broadened into generic value.

NEGATIVE VALUE OF OVERLAP

Preliminary statement.—The successive strata of a formation if preserved to their original limits will be found to have different horizontal extents. The higher beds may overlap farther toward the regions of erosion than the lower, or they may be more restricted; or, turning to the opposite direction, they may extend to greater distances from the source of material. Grabau has discussed these three types under the titles of marine transgressive, marine regressive, and non-marine fluviatile progressive overlap. Certain exceptional cases he further classifies

[3] The topographic features of lake shores. 5th Ann. Rept., U. S. Geol. Surv., 1885, pp. 104-108.

as irregular overlap.[4] The discussion in that paper develops the principles that during the advance of the sea in any cycle of inundation a similar lithologic facies marks the relation of the sea to the shore, and in the case of transgressive overlap the facies farther inland represents a higher geologic horizon. On a retreat of the sea such a shore facies will also retreat while still ascending in the time scale. In the building outward of a river fan, Grabau points out that the upper beds extend beyond the lower and their outer parts rest in turn on the underlying formation. These principles are used, however, not only in discussing the discordance between the lithologic facies and the chronologic succession and in separating the several types of overlap, but as definite criteria for distinguishing marine from terrestrial formations. It is this question of the positive or negative value of overlap, not as general principles of relation, but as definite criteria for separating marine and fluviatile deposits, which it is desired here to discuss.

Transgressive overlap.—It is held in the present paper that transgressive overlap is most commonly marine, but may also be fluviatile and may arise from several causes: first, progress in the normal erosion cycle, especially through the stages of youth and maturity; second, subsidence of the whole region, producing a rise of the ultimate baselevel; third, relative subsidence of the fields of erosion, producing a landward aggradation by rivers, even if there is no invasion by the sea; fourth, a climatic change of such a nature as to steepen the grades of the upper parts of the rivers. A brief discussion of each of these causes is needed, and the citation of examples will make the conclusion more evident.

In the progress of the erosion cycle the waves plane inland to a greater or less extent, save where dammed out by the sediment of powerful rivers. They are eroding and only incidentally depositing agents. If rivers are able to build deltas outward, however, against the sea the inland parts of the delta must also build upward and backward. As the river grade grows flatter and lower with advanced maturity, however, this process is limited and finally comes to an end. With stationary sealevel, therefore, transgressive overlap is unimportant and exceptional, but may be either marine or fluviatile.

A rising sealevel may be due either to marine sedimentation or to crustal changes, lowering the land or raising the sea bottom. The first is a slow and world-wide effect, accompanying the progress of the erosion cycle during a period of quiet. The second is usually more rapid and regional. In either case there will be transgressive overlap. The first commonly but not necessarily results in marine overlap.

[4] Types of sedimentary overlap. Bull. Geol. Soc. America, vol. 17, 1906, p. 569.

Where rivers flowing from high or broad lands are more than able to keep pace with the rising sea and build up their deltas, there will result the construction of continental deposits on the margins of the lands, illustrated by the transgressive overlapping of the fresh-water Potomac formations onto the crystalline floor of the Piedmont plain. Even local and profound subsidence of a geosyncline may not be able to admit the sea, provided the sediment is sufficiently abundant, as seen during the Tertiary history of the Indo-Gangetic plain. Here more than 15,000 feet of fresh-water sediments accumulated and are now exposed through becoming involved in the Himalayan mountain movements.

In the great majority of cases, however, subsidence of the land has resulted in marine inundations and marine transgressive overlap, the waves working directly against the land. This was favored when the lands were low or small in area and the rivers consequently were unable to dam back the rising sea. Such sediment as they have supplied, supplemented by that from marine denudation, has been distributed by waves and currents in the form of marine deposits.

The results of local changes in baselevel are seen in interior basins, where the upper beds extend farther toward the mountains. Among older deposits which have become generally accepted as continental in origin may be cited the Newark formations of New Jersey. Kümmel has shown that the basal formation, the Stockton, does not reach north to the limits of the basin, and he regards the coarse northern beds as belonging probably entirely to the uppermost or Brunswick formation, which in the more southern parts is normally a red shale.[5]

River grades are sensitive indicators of crustal or climatic movements. Any change which causes that part of the river bed between the headwaters and the mouth to fall below grade will cause the building of river deposits which will give the appearance of transgressive overlap. Any change which causes that part to be above grade will result in a shifting downstream of the deposits and give rise to regressive overlap. Illustrations are seen in the alternate filling and cutting during the Pleistocene of rivers flowing across Piedmont slopes. Transgressive or regressive overlap toward the source of supply consequently can not be used in itself as a criterion of either the marine or continental origin of deposits. The nature of these must be determined by other criteria, and then the nature of the overlap takes on great significance in regard to the conditions which supplied the waste.

Overlap away from the source of supply.—Overlap away from the source of supply, which Grabau regards as establishing the fluviatile ori-

[5] Annual Report of the State Geologist of New Jersey, 1898, p. 48.

gin of the strata beyond contravention,[6] occurs where a certain facies—for example, the Catskill facies of the Upper Devonian—advances progressively farther from the direction of supply, the higher beds gradually displacing the Chemung facies from New York and central Pennsylvania. But the Catskill facies began in fact in the Oneonta formation, and in the upper part of this it can not be said that overlap away from the source of supply was exhibited. The Oneonta is separated from the overlying Catskill by a landward retreat of the non-marine beds, an accompanying incursion of the marine beds, the basal Chemung. Subsidence for a time gained on sedimentation, and the direction of overlap is seen to be due to the relative dominance of opposing factors. These must be more fully discussed under the topic of the delta cycle.

Mud and sand may be worked by waves and currents to indefinite distances from shore, the only condition being that the bottom must be sufficiently shallow to be affected by waves. In the case of epicontinental seas this is commonly true for much of or even the whole area. Mud settles from suspension for some distance, also, beyond these limits, and at the present time gives rise to the blue muds which mantle the slopes of the ocean basins to distances of from 100 to 200 miles beyond the limits of the wave-worked bottom.

In the Arabian Sea such muds in fact are carried from 700 to 800 miles from land, owing to the character of the ocean currents. Further, it has been noted that in the direction of the prevailing winds desert dust is carried from the Sahara and from Australia for hundreds of miles from land and to such an extent as to visibly affect the air and the color of the water. Applying these observations to the past, it is seen that where uplift of an old land takes place without a shallowing of the sea, marine sands and clays will be spread over areas where previously there was a development of limestones. This does not carry any implication in regard to a movement of the shoreline and, provided the water is fairly deep and the waste is fine, deltas may not be built seaward in marked degree. If the sea was originally so deep that its bottom was but little affected by waves, the shallowing of the sea by uplift or sedimentation may cause a progressive advance of marine clastic sediments away from the source of supply. This is to be noted, for example, in the Upper Ordovician, where the deposition of argillaceous sediment gradually displaced that of limestone toward the west.[7] Grabau cites the Pottsville of the Appalachians as a group of formations whose conti-

[6] Op. cit., p. 636.

[7] E. O. Ulrich: Revision of the Paleozoic systems. Bull. Geol. Soc. America, vol. 22, 1911, p. 296.

nental origin as a whole he regards as demonstrated from the fact that the higher formations overlap northwestward.[8] But that this is not proved is indicated by the existence of a brachiopod fauna in the Middle Pottsville (Horsepen) as far north as Sewell, on New River, and less conclusively by the occurrence of *Naiadites* and *Spirorbis* in the Lower Lykens group of the Anthracite region.[9] David White also reports other localities and horizons which contain marine invertebrates. The present writer holds that the beds of coal and the heavy conglomerate horizons are clearly continental, and this implies that some part of the remainder is also fluviatile. In the north and east this is thought to apply to practically the whole of the formation; but the marine faunas, more abundant in the south and west, prove at least a considerable proportion of marine beds in that region. The great thicknesses which the Pottsville attains in the southern Appalachians, from 2,000 to 6,000 feet, clearly indicates that the level of the upper surface was as much controlled by subsidence, which tended repeatedly to bring in the sea, as by river upbuilding, tending to raise the surface above sealevel.

From these examples it is seen that overlap away from the source of supply can not be used as a criterion of continental or marine origin any more than transgressive or regressive overlap, but may be due to regional subsidence or tilting or a climatic change which shifts clastic material of a certain kind progressively farther from the source of supply.[10]

THE DELTA CYCLE AND ITS USE AS A CRITERION OF ORIGIN

Comparison of the erosional and depositional theories.—Previous to the recognition of the principle of baseleveling and the key which it offered to the erosional history of the lands, the processes of river erosion as elaborated in geologic texts were essentially detailed descriptions, unrelated to a law which should connect the sequential stages into a cycle of erosion. The recognition of that principle has raised the subject from the descriptive and qualitative to the quantitative and predictive plane and permits the erosion history to be read in terms of time and crustal movement, modified by the factors of climate and rock structure.

But a graded river consists ideally of three parts: its upper waters are erosive agents, its middle waters are fully engaged in transportation of the rock detritus, and its lower waters deposit part of the burden before

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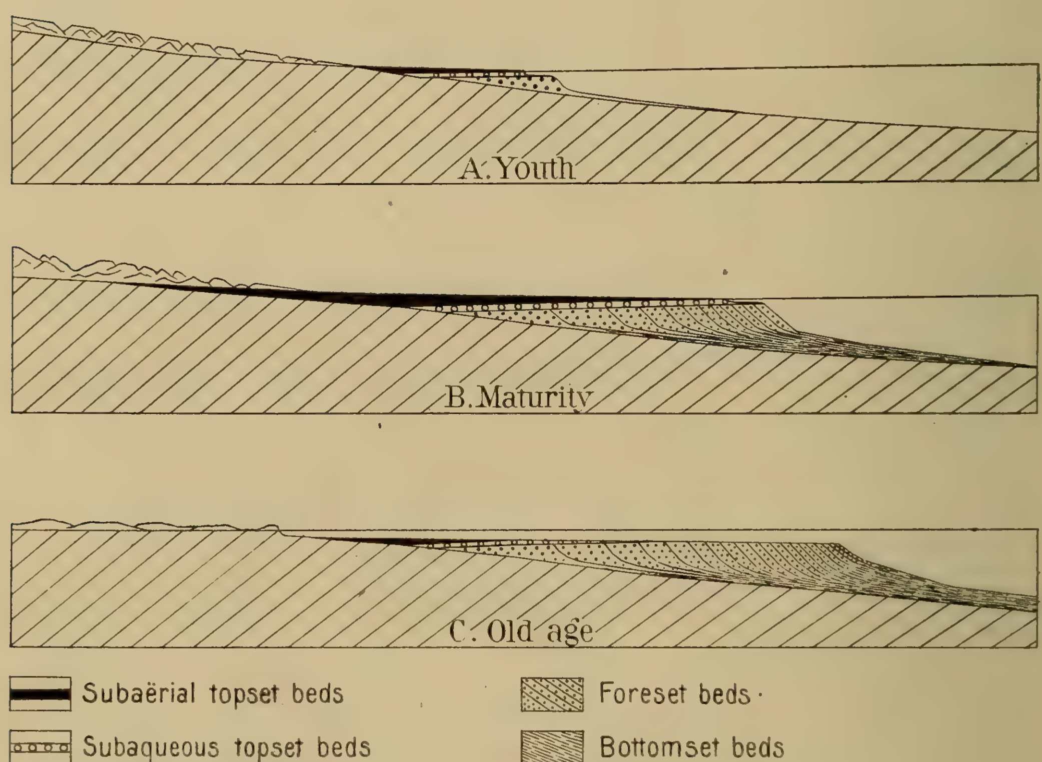
[8] Types of sedimentary overlap, pp. 634, 636.

[9] David White: Deposition of the Appalachian Pottsville. Bull Geol. Soc. America, vol. 15, 1904, pp. 277, 280.

[10] The relations of climate to overlap have been more fully discussed by the writer in another paper, "The relations between climate and terrestrial deposits," part III. Journal of Geology, vol. xvi, 1908, pp. 363-384.

the river merges into the sea. The whole is epitomized in the waste-laden waters which converge into the mountain gorge and then, escaping and diverging, deposit a part of their burden on the alluvial fan. The recognition of the erosion cycle and the separate processes of valley deepening and valley widening has stimulated wonderfully the science of physiography, but it is to be noted that no corresponding deposition cycle has been elaborated to a similar degree to connect the successive stages in the work of the lower parts of the river, the descriptions of deltas being still essentially in the state in which they were left by Charles Lyell.



Vertical scale magnified several hundred times

FIGURE 3.—*Diagrams showing Stages in the Delta Cycle of a large River during a Period of stationary Crust*

In studying the surface of the land the need for the formulation of a delta cycle has not been felt, since the successive stages are concealed by burial, but for the interpretation of the sedimentary record it becomes of considerable importance. As a preliminary step for the evaluation of the criteria of ancient delta deposits it is desirable, therefore, to formulate such a deposition cycle in reversed terms to the erosion cycle of the upper waters.

The river is assumed to begin its work on a tilted continental surface, which slopes gently beneath the sealevel and gives a wide area of shallow bottom. This is an initial attitude, which has resulted frequently from periodic diastrophism through geologic time, and the majority of formations open to observation have been deposited near the shores or on the bottoms of interior shallow seas, where waves and currents were consequently less effective than on the outer slopes of the continent. The delta cycle may then be divided into two phases: first, the normal cycle dependent on deposition with a stationary crust, and, second, the modification imposed by vertical movement of the bottom—normally subsidence, abnormally elevation. The subject of the relations of deltas to sedimentation has been previously discussed by the writer,[11] so that a condensed formulation will here suffice, bringing out more particularly the principle of the cycle.

Delta cycle with stationary crust (see figure 3).—In the stage of youth before the drainage system has become well developed the detritus delivered at the river mouth is somewhat smaller in amount but coarser in texture. The subaqueous wave-cut profile is also undeveloped, the bottom still inheriting its original slope. If this initial slope is gentler than the subaqueous profile of equilibrium[12] the waves have at first less power of erosion at the coast line. If the initial slope is steeper they will possess an initially greater power. Assuming, however, that the river is dominant over the sea, the delta is rapidly built outward, and on account of the coarse waste, the steeper river grades, and shallow bottom near shore, the initial proportion of subaerial topset beds is relatively high. During maturity the quantity of waste is larger, as all parts of the drainage system now supply sediment, but as the river is graded and its gradient is also flattened the waste is finer in texture. The delta is extended outward and the greater deposit is on the outer portions. It grows inland also for a time, but owing to the flattening grade the beds in this direction show decreasing thickness. The maximum *rate* of outward growth is reached early because of the increasing surface area, which requires a greater volume of sediment to give a unit thickness, and the increasing depth of the water, which involves a continually deeper fill. Furthermore, the increasing shoreline and greater exposure to the waves increase the power of the latter to carry away the waste, which with the progress of the cycle becomes finer in texture and more readily removed

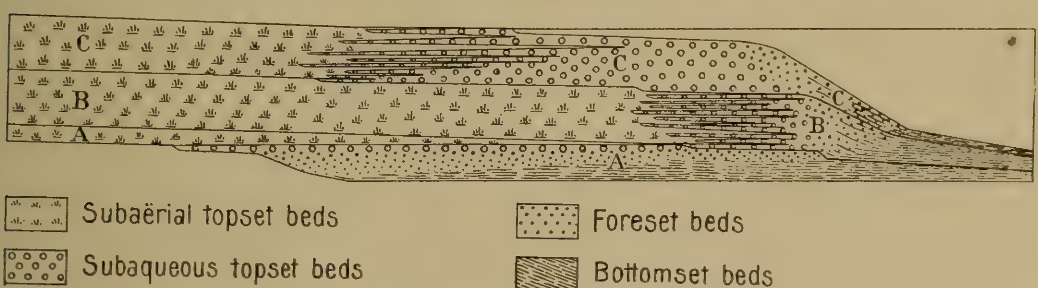
[11] Relative geological importance of continental, littoral, and marine sedimentation. Journal of Geology, vol. xiv, 1906, pp. 336-354.

[12] N. M. Fenneman: Development of the profile of equilibrium of the subaqueous shore terrace. Journal of Geology, vol. x, 1902, pp. 1-32.

by the sea. But although the rate of advance falls off, the outward growth will continue during the progress of maturity in the cycle of erosion and deposition. In old age, however, on account of the ever slackening supply of waste and the larger proportion carried in suspension and solution, the sea at last gains the mastery and begins to plane inland across the low-lying and unconsolidated materials projecting into the sea. Rapid headway is finally made against the weakened river; the territory conquered by the river in its youth is reclaimed and the sea at last will beat once more against the margin of the old land. Thus far the assumption which has underlain the discussion is that a constant sea-level has prevailed. But in so far as the initial land uplift was far extended there will follow a resultant simultaneous erosion of the land and filling of the sea by river waste from many lands. During the progress of the cycle there will result therefore from erosion of the lands, even with a stationary crust, an appreciable rising of the sea, as pointed out by Suess and Chamberlin. This conclusion from deduction is in accord with the observations in regard to the characteristic transgressive overlapping of marine formations laid down during a period of crustal quiet. Because of the ratio of land to sea the elevation of the sealevel may amount to about one-third of the lowering of the average land level. The elevation of sealevel without diastrophic cause may therefore readily be an amount greater than the depth of wave base. Consequently such a condition should be added to the discussion of the delta cycle with stationary crust. This is illustrated in the figure, where it is seen that notwithstanding the final destruction of the upper beds of the delta by marine planation a certain amount of subaerial beds may be preserved below the wave base. From the factors which control delta growth and the nature of that growth as a warfare between the rivers and the sea, it is seen that in periods of quiet and low-land relief deltas might nearly disappear from the physiography of the earth. At other times, when the relief of the continents, especially through mountain-making movements, was greatly increased and erosion quickened without elevation of the negative elements of the continent, the building of deltas may have risen to a dominant mode of sedimentation rivaling in volume the marine deposits. Such physiographic conditions characterized especially the Upper Devonian and later periods of the Paleozoic. They are found in connection with the late Cretaceous movements of western North America. In Eurasia they became pronounced in the Oligocene and early Miocene, when mountain-making prevailed and the great regional uplifts of the Neocene had not yet begun. The application of the principle of the delta cycle brings into truer perspective many fresh-water deposits

of those geologic periods with their marine intercalations and offshore equivalents.

Result of a movement of subsidence.—Movements of subsidence, perhaps attended farther inland by elevation, rather commonly, however, rejuvenate the delta cycle before it has passed beyond the stage of maturity, causing new beds to be built on top of the old and burying the older part below the reach of surface agencies. Where the delta surface is very large and the movements of subsidence are intermittent but progressive, each downward movement will bring in the sea, each pause will witness it crowded back. The result on the whole will be an upbuilding rather than an outbuilding of the delta. Figure 4 shows in such a case how dominant the topset beds become, constituting the greater part of the delta volume, whereas in outward growth with stationary water level the foreset beds because of their steeper slope are volumetrically of more importance, sharply distinguishing the two modes of delta-building. The great depth of fresh-water beds and old soils in the greater deltas



Vertical scale magnified several hundred times

FIGURE 4.—*Relations between Mode of Delta-building and Subsidence*

First stage.—Delta built out into water of constant level; basin deeper than wave base. No subsidence. Dominance of foreset beds. Increasing importance of topset beds, shallowing of basin, and decreasing importance of foreset beds.

Second stage.—Intermittent subsidence balanced by deposition. Delta built upward, not outward. Dominance of topset beds.

Third stage.—Subsidence at a faster rate, maintaining a larger ratio of subaqueous topset beds.

of the present period, extending in many cases hundreds of feet below sealevel, shows that this is a common feature of delta growth. It is natural, furthermore, that such should be the case, since the great rivers tend to drain toward subsiding areas and their sediment promotes further subsidence. It is a mode of delta growth which is wholly lacking where small deltas are built into lakes of stationary level. This feature of the larger modern deltas indicates how the great depth of certain fresh-water deposits of the older geological periods may be interpreted as delta formations, shading off into the contemporary marine deposits of epicontinental seas.

Observation of river valleys and shorelines shows that crust movements are relatively rapid between longer epochs of quiet. Stages in subsidence will therefore result in wide and geologically rapid transgressions by the sea over the subaerial delta plain. But such individual downward movements are commonly small in amount, so that the volume of sea water on the delta surface is correspondingly small and is soon excluded by the readvance of the subaerial plain of the delta. The effect of individual movements of subsidence is therefore to greatly extend for a short time the subaqueous portion of the topset plain and result in an extremely unstable shoreline. From this argument it follows that evidences of either marine or continental origin of a certain stratum carry but little implication in regard to the origin of inferior or superior portions of the formation. This is illustrated by the Illinois coal measures, where limestones holding abundant marine fossils are found repeatedly and closely to overlie coal beds. Furthermore, a definite criterion of origin, such as roots or mud cracks, if scattered vertically through a whole formation, is seen to be much more significant of the dominant mode of origin than is a unique stratum which nevertheless may be rich in evidence.

In order to bring the idea of the delta cycle to a workable agreement with nature there must be considered the presence also of uplifts in the crustal movements. Field investigations of the past decade have been giving a continually larger place to disconformities, stages of lost record. The Paleozoic seas were shifting water bodies and many times receded from the land. Detailed work on the Mesozoic of the coastal plain shows breaks representing long time intervals which separate the several late Jurassic and Lower Cretaceous fresh-water formations. The Pleistocene crustal oscillations also involved repeated reversals of the dominant trend in the movement.

Applying the idea of upward phases in downward crustal movements to the problem of delta growth, it is seen that in the case of a delta with distinctive foreset and topset beds a slight upward movement should result in a disconformity over the inland portion of the delta. The erosion plane may vanish to seaward, giving place to land beds overlying parts of the former subaqueous plain. A slightly greater movement, however, will carry the disconformity to the foreset edge. In either case a great increase in the volume of the marine foreset beds for a certain stage marks the uplift of the delta and corresponds with the erosion and lost record on its topset plain. If, as seems to have been a rather common condition, the epicontinental sea was so shallow as to prevent the formation of a distinct foreset slope, then the slight regional uplift would

merely shift the topset beds farther seaward and, owing to the rapid movement of unconsolidated material, produce possibly a lens of terrestrial deposit when previously the sedimentation of that zone had been wholly marine. Oscillation, therefore, will shift the zone of maximum deposition back and forth. Slow subsidence favors great depths and volume of topset beds, a considerable percentage of which is, however, marine, although the absolute amount of terrestrial deposits is at the same time greatly increased. Small uplifts favor great volumes of foreset beds and tend to shift farther seaward the zone of terrestrial sedimentation.

Imperfect application to present conditions—Effects of recent crustal movements.—A crustal uplift which interrupts an erosion cycle and initiates a new baselevel brings about a destruction of the former baselevel forms, but only in a time interval comparable to that which developed them. A long cycle, for example, reduces hard rocks to a peneplain, remnants of which persist for another long period of time. This persistence of topographic forms permits the study of the physiographic history of the upper parts of the river systems backward through several erosion cycles of increasing time intervals. It is not true to the same degree with delta growth. Such structures are built against the sea and feel immediately the effects of crust movements. They consist of unconsolidated materials and rapidly suffer from erosion or burial under changed conditions due to crust movements. The subcycles which interrupt the orderly progress of surface processes are thus peculiarly magnified in the case of deltas and the sequence of successive stages can best be studied in the upturned and partly eroded older formations rather than in the delta which still lies beneath our feet.

At the present time, as a result of the great Pleistocene uplifts, followed by the Recent oscillations and partial subsidence which mark the later Cenozoic as a period of world-wide crustal unrest, the rivers are out of adjustment with the present sealevel. The streams are intrenched in inner rock gorges, most piedmont alluvial slopes have become dissected, river valleys have been turned into estuaries, lakes have arisen in inland basins, many deltas have been partly drowned, and, as seen especially around the shores of Asia, the rivers are just beginning to again reclaim their subaerial plains from the last submergence. Certain ones, however, like those of the Ganges, Indus, and Nile, have maintained their fronts at the limits set by the deep water of the ocean. Since the early Tertiary, furthermore, the interior shallow seas which in the earlier geological ages were the favored regions for delta growth have been very largely excluded from the warped and uplifted continents. For all these

reasons the deltas of the present time are in a peculiarly disordered state. Without the aid given by a deductive analysis of the delta cycle they give but little clue to the place held in the scheme of sedimentation by deltas during the earlier geologic ages.

Resulting overemphasis of estuarine conditions.—The impress of recent broad crustal disturbances on the present surface forms of the world was not fully perceived until after the principle of baseleveling by fluviatile erosion had become accepted. Then it was seen that though peneplains in various degrees of preservation existed in many regions, they were out of adjustment with the present baselevels and were being destroyed instead of perfected by the newly initiated cycle of erosion. This fact, which was at first used as an argument against the competence of streams to produce peneplains, was shown by Davis to be, on the contrary, an evidence of recent profound crustal disturbances. Other evidences of the present physiographic youth of the lands are seen in the existence of basin lakes of non-glacial origin and in estuaries. It has become well recognized that lakes are impermanent geological features, and that fluviatile deposition is a more normal mode of continental sedimentation than is lacustrine. In the literature of paleontology and stratigraphy, however, the estuarine idea still plays an unduly large part in the interpretation of the past.

An estuary, according to the dictionaries, is an enlargement of a river channel near its mouth, in which the movement of the tides is very prominent. The principal existing estuaries—such, for example, as the Saint Lawrence and the Thames—are all the result of recent coastal subsidence and the drowning of the lower river valleys. The same movement that resulted in the Gulf of Saint Lawrence has produced Long Island Sound, Delaware, and Chesapeake bays; bodies of water which show various degrees of salinity. They all bear the common marks of being old river valleys trenched within uplands, and represent a reversal from erosion to deposition so recent that the sediment carried in by the rivers has not been sufficient to fill in the ancient valley. Tidal action tends to keep open larger channels and maintain a greater depth of water than waves alone could do, but tides do not account for the origin of the present estuaries and will not prevent infilling with sediment. On the contrary, the tides are effective agents in the restriction of broad estuaries by building up tidal marshes. In the most striking example, the Bay of Fundy, Lyell speaks of the rapid growth of tidal marshes from the sediment precipitated on their surfaces at flood tide. In what were once smaller estuaries, as at the mouth of the Savannah River, with a tidal range of 7 feet, the coast chart shows how the estuary has been

converted into salt marshes, drained by a network of tidal channels. Thus the present complexities of the coasts broken by bays and estuaries is a phenomenon as abnormal and geologically as temporary as the warped and elevated peneplains which are beginning to be dissected. They can not be safely used as illustrations for the interpretation of ancient deposits, many of which were made during stages of crustal quiet and low-land relief.

In most of the so-called estuarine deposits of earlier geologic periods there is in reality no evidence of tides nor of deposition within submerged valleys previously eroded by rivers. Where modified marine faunas indicate brackish water conditions, the present knowledge of the physiography of earlier periods would point more commonly to partially isolated bodies of shallow water existing because of downwarps of the land, similar to Hudson Bay and the Baltic Sea. In other cases, however, it is probable that depauperated marine faunas associated with fresh-water material may represent that combination of lagoon and fluviatile conditions which marks the flat outer portions of large deltas. Such lakes, bays, and sounds are well developed on the margins of the Mississippi delta. The shifting of river channels and the pouring in of flood waters serve to change greatly and suddenly the salinity of such restricted water bodies and must produce environments especially variable and trying to their inhabitants.

It would seem from the discussion of the delta cycle and its relation to diastrophism and sedimentation that the term "estuarine deposit" is very poorly chosen, and as a term of broad application should be avoided. It must be confessed, however, that there is no entirely satisfactory substitute, since the words lagoon, bay, sound, and sea are in the English language without sharply defined meaning. The word bay properly used is, however, the best of these terms. Bays are smaller and more inclosed water bodies than seas. Shallow seas and bays are normal physiographic features of those continental elements which lie near sealevel. Bay formations may therefore be laid down in irregular invasions by the sea over a land of no relief or in the partially inclosed water bodies which result from delta-building, an invasion by the land against the shallow sea.

Modern illustrations of ancient interior deltas.—During the Paleozoic the rivers commonly flowed into wide and shallow interior seas. The latter no longer exist save in such restricted examples as the Baltic and Hudson Bay, and into these no large rivers pour abundant waste. But the recently submerged margins of certain deltas, or other conditions inaugurating broad shallow waters, do bring about locally and tem-

porarily these common ancient conditions. The Hoang Ho, now pushing out rapidly into the Gulf of Pe-Che-Lee, faces a water body less than 40 meters deep. The Terek, loaded with waste from the Caucasus, is building into the Caspian in waters less than 20 meters deep. The Jaxartes and the Oxus are rapidly filling the Aral Sea, a shallow remnant of the recently large interior Eurasian Sea. In all of these the shore face is 5 meters or even less in depth, and a highly irregular shore line testifies to the dominance of the river over the weakened wave action. In the more protected parts of the shoreline the water shallows without a definite boundary, but there is an absence of lagoons behind barrier beaches.

Another excellent example which illustrates conditions of waste-bearing rivers pouring into very shallow waters is seen within the central Andes, in Lake Titicaca, for details concerning which the writer has had the advantage of personal discussion with Prof. Isaiah Bowman.* This body of water is 100 miles long by 30 broad and in the central part ranges from 350 to 900 feet in depth.† But at the two ends of the lake are broad areas averaging from 15 to 30 feet in depth. The Bay of Puno at one end and Lago Pequeño at the other are so nearly isolated that the maintenance of such shallow water in them can not be ascribed to wave action from the open lake, especially as rivers bearing a moderate amount of alluvium flow into these bays. The striking feature about the shore of Titicaca is the meagerness of shore erosion in general and its complete absence on much of the shores which face these broad shallow waters. Here, where the old alluvial plains slope under water, a belt of clear quiet water is succeeded at a depth of several feet by a broad thick belt of water grasses, within which, during the seasons when the land pasturage is scant, the cattle revel like amphibious creatures.

The grasses grow only on shallows which are permanently covered by water and protected from heavy wave action. On the northwest shore they are found facing the open lake only where protected by the shallow water of the drowned delta plain of the Suchis River. Thus from the evidence of Titicaca it is seen that facing shallow bottoms subaqueous vegetation, at least in fresh waters, may effectively hold river muds from attack by waves.

Even where water grass does not protect the shore the waves, where the adjacent bottom consists of broad shallows, show but little power of erosion, for the road along which the prehistoric builders of Tiahuanaco

* See a forthcoming paper by him on Lake Titicaca and the ruins of Tiahuanaco.

† For map see Geographical Journal, vol. 37, 1910, map on p. 512. See text on pp. 398-404.

carried the stone for their buildings at a date estimated at thousands of years ago (placed by Professor Bowman at probably 5,000 to 6,000 years) is still in existence, though in skirting around the south shore it obviously kept close to the water.

An excellent example of a delta which has been built into shallow water of constant level is that of the Saint Clair River.‡ Lake Saint Clair has a maximum depth of 22 feet, and except on the side of the delta the water deepens within a mile of the smoothly curved shore to 2 fathoms, the mark of the local wave base. The delta is built of fine-grained waste derived by wave action on the shores of Lake Huron and current action on the banks of the Saint Clair River. Its front does not show the crescentic reefs due to wave action. Shoal water of less than 1 fathom in depth extends outward from 2 to 4 miles from the main area and from 1 to 2 miles beyond the mouths of the distributaries. The lagoons thus arise from inclosure between growing distributaries rather than behind a shore barrier. There is less water completely shut off, however, than in the case of strong wave action. From the margin of the shallow water the front slopes rapidly to 2 fathoms, the normal depth of the lake.

This forms a good measure of the limits of shoal water between the land and the shore face in a delta built under conditions which make this transition zone a maximum, since here the waste is fine, is not flocculated by salt water, and the wave action is weak.

These marginal conditions of deltas built into shallow waters with weak wave action may be contrasted with those described for the Nile, the Mississippi, and other large deltas built out against the oceans. In earlier ages at stages of stationary crust and constant water level the deltas of interior seas would build out until shallow protected waters would disappear and they would invade a region of constantly stronger wave action. The sea would more and more tend to limit their growth. Such a stage is now seen in the deltas facing the North Sea. Following a movement of subsidence the contrary phase would occur; shallow waters would pass far inland and the delta conditions would come for the time to resemble those of the Yellow, Aral, and Caspian seas. Thus there would be expected a cyclic oscillation in the character of the delta front.

The late Mesozoic delta cycle of the Atlantic Coastal Plain.—The determination of the conditions of origin of a particular formation or part of a formation depends in the first place on the study of the strata and the application to them of detailed criteria; but after this is done the

‡ L. J. Cole: The delta of the Saint Clair River. Geol. Surv. Mich., vol. ix, pt. I, 1903.

conclusion as to the larger relations and the decision as to an estuarine, delta, lacustrine, or other mode of origin should be tested further by another set of criteria derived by comparing the broader relations of sedimentation under those different conditions. The previous discussion has pointed to the large place which delta formations should occupy under conditions which have not uncommonly occurred through geologic history, and it is to be concluded that in statements as to mode of origin conditions of lacustrine and estuarine deposition have been too freely invoked and without adequate proof. On the other hand, fluviatile deposition on deltas or in basins has not received proper recognition, qualifying this statement, however, with the corollary that the shallow pans of more or less permanent water on floodplains give minor lacustrine phases connected with fluviatile aggradation.

The principle of the delta cycle may, accordingly, be used as one criterion of the mode of origin, and, as an illustration, it will be applied to the late-Mesozoic deposits of the Atlantic Coastal Plain. It will be seen to bring forth different conclusions from those stated in the publications regarding these formations. It is possible to discuss the problem of origin only because of the excellent and authoritative stratigraphic work done in recent years by Darton, Clark, Kümmel, Shattuck, Miller, Bibbins, and others. Their field work is here wholly accepted and the discussion turns merely on the interpretation as to origin.

Sedimentation began near the close of the Jurassic* as a result of a crust tilting, which brought the old crystalline floor somewhat below baselevel. Repeated movements of partial uplift alternated with continued depression, so that the formations are separated by unconformities which may represent longer intervals of time than the deposition of the sediments. The conditions of sedimentation remained much alike, however, through late Jurassic and Lower Cretaceous time and resulted in the formation of the Potomac group, which recent studies have separated into four formations—the Patuxent, Arundel, Patapsco, and Raritan. These and the succeeding deposits are well described in the Patuxent and Philadelphia folios, so that a full description may be omitted from the present paper. There is preserved throughout the group a diversified land flora. Less abundant remains of a land fauna are present, but no marine fauna. Above the Potomac group occurs the Magothy formation. It is characterized by the occurrence in places of a marine fauna, as in the vicinity of Raritan Bay, New Jersey, but no marine fossils have been observed to the southward, extending from Burlington County, New Jersey, into Maryland. The Magothy contains also, however, a

* By some geologists regarded as earliest Comanche.

land flora, and in its sedimentary character is transitional between the fresh-water deposits below and the typical marine formations of the Upper Cretaceous which overlie it. A summary statement of these Mesozoic formations is repeated here from the columnar section of the Patuxent folio.

UPPER CRETACEOUS

Monmouth formation, 40 to 50 feet.
Reddish-brown and greenish-black sand, with many irregular iron crusts.

Matawan formation, 45 to 50 feet.
Gray and black micaceous sandy clay carrying glauconite.

Unconformity

Magothy formation, 0 to 40 feet.
Thinly laminated sand and clay, with much lignite and occasional ferruginous sandstone.

Unconformity

LOWER CRETACEOUS

Raritan formation, 100 feet.
Variegated clay, sand, and gravel, with some lignite.

Unconformity

Patapsco formation, 100 feet.
Highly colored variegated clay interbedded with sand and gravel.

Unconformity

JURASSIC

Arundel formation, 0 to 125 feet.
Drab, red, and black clay carrying lignite and iron ore.

Unconformity

Patuxent formation, 340 feet.
Light-colored, arkosic sands, with clay lenses and gravel bands

Unconformity

ARCHEAN

In regard to the interpretations given as to the conditions of sedimentation the following statements are quoted from the Patuxent folio, pages 9 and 10, published in 1907:

"Potomac history.—The earliest of the known unconsolidated deposits lying upon the floor of crystalline rocks belong to the Patuxent formation of the Potomac group. . . . It indicates a submergence of the Coastal Plain in this region of sufficient extent to cover the whole area with shallow water. The cross-bedded sands and gravels furnish evidence of shifting currents, as do also the abrupt changes in the character of the materials, both horizontally and vertically. The presence of numerous land plants in the laminated clays shows the proximity of the land."

The Arundel formation was deposited within stream valleys which had become eroded into the Patuxent. The Patapsco and Raritan are, however, like the Patuxent, widely developed formations and were deposited under similar conditions. These four formations constitute the Potomac group.

"The widespread development of shallow-water deposits, everywhere cross-bedded and extremely variable in lithologic character, and the presence throughout these deposits of land plants furnish some evidence that the Potomac sedimentation took place not in open ocean waters, but in brackish- or fresh-water estuaries and marshes that were directly connected with the ocean, which may have at times locally broken into the area. Some land barrier to the east of the present shoreline probably existed and produced these conditions, but its position and extent can not be determined.

"The period during which the Magothy deposits were formed was one of transition from the estuarine or fresh-water conditions of Patapsco and Raritan time to the marine conditions under which the Matawan, Monmouth, and Rancocas were laid down. . . . The probability is that over most of the area where Magothy deposits are now present Potomac conditions prevailed during the greater part of the period, and in some places perhaps during the whole of it, but that occasionally, through the breaking down of the land barriers which had kept out the ocean, there were incursions of sea water, bringing in marine forms of life. Thus far there is no evidence that such incursions took place anywhere except in New Jersey.

"Later Cretaceous history.—Not until late Cretaceous time did a downward movement occur of sufficient extent to permit the ocean waters to transgress widely over this region. During the Matawan, Monmouth, and Rancocas epochs probably all of the quadrangle was depressed beneath the ocean waters."

From these statements it is seen that an estuarine origin is invoked as far as possible, though marsh conditions are granted for the Arundel formation, which was discontinuous in its original development and deposited apparently in river valleys cut through the older deposits. That the estuarine interpretation for these formations is dominant in geologic thought is illustrated also by quotations from the Philadelphia (Pennsylvania, New Jersey, Delaware) folio, page 18, under date of 1909. Here the possibility of marsh conditions is not noted, and it is merely stated that

"toward the close of Jurassic time and at the opening of the succeeding period—the Cretaceous—estuarine conditions are known to have prevailed. . . . About the middle of Cretaceous time the barrier between the Delaware estuary and the sea disappeared and the Paleozoic crystallines bearing a cover of early Cretaceous deposits were submerged beneath the Atlantic."

In the statements as to the mode of origin of these formations there has thus far been no pro and con discussion as to the possibility of a terrestrial and fluviatile as opposed to an estuarine and subaqueous origin. Rather the assumption of earlier times as to the accumulation of all sediment in bodies of standing water has been carried forward to the present. That of lacustrine origin has apparently been ruled out by the gradation which occurs in the Upper Cretaceous from fresh water into truly marine formations. The assumed existence of a land barrier lying to the east of the present Coastal Plain rests merely on the initial hypothesis of an estuary from which the sea must be barred save at the mouth.

As defined in standard works on the English language, an estuary is that part of the mouth or lower course of a river flowing into the sea which is subject to tides, and as argued in a previous section is the result of a recent marginal subsidence affecting lands of considerable relief. The late Mesozoic deposits of the Atlantic coast in contrast to these conditions began to be deposited on a fairly developed peneplain. The formations outcrop parallel to the Appalachian system from Massachusetts to the Mississippi Valley and are thicker toward the sea, giving no hint of a barrier to the southeast, but indicating rather that subsidence of the coast was accompanied by upwarp of the interior. These formations, furthermore, according to all observers, give evidence of shallow waters, with an absence of marine faunas through late Jurassic and Lower Cretaceous time. They were deposited therefore not in drowned valleys radiating away from the mountains, but as a marginal fringe, where the old land was depressed below baselevel. There is none of the physiographic setting of estuarine conditions. On the contrary, terrestrial and fluviatile deposition is suggested by the following features: The individual strata are markedly discontinuous, beds and lenses of clay and gravel occurring in sandstone and vice versa. Highly variegated clays are abundant, in which the state of the iron oxide varies from stratum to stratum and laterally through the same stratum, indicating varying facilities for oxidation, both vertically and laterally. Segregations of iron ore are abundant at many horizons, and the writer has noted the patterns of shrinkage cracks in certain of the plates of ore. The abundant leaf impression, the lignitized and silicified wood, and the ap-

parent absence of marine, brackish water, or even lacustrine faunas from nearly the whole group show deposition in the vicinity of plant growth and the presumed absence of permanent water bodies. In the Arundel formation gypsum has been found. The bones of dinosaurs, turtles, and crocodiles are fairly abundant, and occasionally large stumps are discovered standing in the position in which they grew. Ascending through the formations, however, the suggestions of fluviatile and terrestrial sedimentation weaken in the Raritan, where logs of lignitized conifers exhibiting teredo borings have occasionally been found, and in the overlying Magothy, as previously noted, the first clearly marine fauna occurs. The value of these stratigraphic characters as criteria of fluviatile deposition is discussed in the second part of this article, but they are mentioned here to show that the suggestions derived from the strata as well as from the larger relations are those of a fluviatile rather than an estuarine origin.

The review of these characters permits the application of the principles discussed under the delta cycle as an explanation which connects the physiographic relations of the Appalachians and the Coastal Plain with the sequence of the formations and the final passage into marine conditions. A new interpretation may then be given as follows: At the beginning of sedimentation broad interior uplift was more pronounced than subsidence of the Coastal Plain. This resulted in a dominance of sedimentation over marine transgression and a maintenance of the coast line beyond the present limits of observation. The rivers were spaced at sufficiently short distances, so that the deltas were confluent as a flat Piedmont Coastal Plain, probably with a highly irregular and shifting shoreline; but the entire absence of marine incursions between the larger delta units or across their upper surfaces and the recurrence of unconformities suggest that what is now exposed was the landward side of a great alluvial plain and the shore was continually maintained farther seaward. If it were possible to follow the evidence beneath the present sea the unconformities might be found to pass into terrestrial beds of equivalent time value and the intervening formations which make up the Potomac group might be found to pass seaward into marine topset beds between the terrestrial intercalations. If there were in reality an axis of no subsidence on the southeast during the Mesozoic, where now is open water, to serve as a barrier, the deposition took place in a basin rather than an estuary and maintained the region as the alluvial plain of the trunk river which flowed through it. But of such a barrier there is no structural suggestion nor theoretic need.

During Cretaceous time subsidence became more marked than tilting,

as shown by the overlap of the Patapsco formation on the ancient rock floor north of Philadelphia. Erosion was therefore weakening and the sea was gaining more power. Consequently by the beginning of Upper Cretaceous time the shoreline had advanced inland, oscillating over the present limits of the Coastal Plain and laying down the Magothy formation. Then the sea, gaining headway, planed still farther inland and gave rise to the marine formations of the Upper Cretaceous and Eocene. These, if they could be restored to their original shoreward limits, might possibly be found to contain at certain horizons restricted terrestrial deposits. The marls, glauconitic sands and clays, and diatomaceous earths suggest, however, that sedimentation became so slack that the sea probably planed inland and closed completely the delta cycle. The oscillations and subsidence shown by the stratigraphic record follow the outline previously given for the theoretic delta cycle, but there is here imposed as a further condition a tilting; uplift accentuating erosion inland, while toward the margin of the continent subsidence made more room for deposition of terrestrial beds. This condition is a not uncommon one in crust movements, tilting without regional subsidence acting to prolong the life of the delta cycle. In this case it lasted through late Jurassic and all of Lower Cretaceous time.

If the interpretation here offered shall be found to be an advance on previous conceptions it will justify to that degree the use of the theory of the delta cycle as a criterion of interpretation.

CONTRAST OF MESOZOIC AND PALEOZOIC DELTA CONDITIONS IN THE APPALACHIAN PROVINCE

During the Paleozoic the zone of uplift of the Appalachians, rejuvenated by successive movements, lay over the present Piedmont Plateau, the Coastal Plain, and doubtless still farther east over a region now covered by the sea. The regional uplifts were doubtless varied in nature but were several times of an orogenic character, mountain axes being separated by such intermontane depressions as the Narragansett and New Brunswick basins. To the west of this ancient land of Appalachia lay a great axis of subsidence which, as a result of the transformations wrought through geologic time, has since the Paleozoic, and especially in the Cenozoic, assumed the position of maximum uplift. No evidence is available as to the distance to which the land extended toward what is now the open ocean, and the sediments swept from it in that direction are lost to observation. The formations which are accessible are those laid down to the west and represent that portion of the Appalachian detritus which was swept inland, largely trapped within the adjacent

geosyncline, but spreading to some extent beyond it over the continental interior.

By the late Mesozoic the conditions had become reversed. The old land of Appalachia now became a region of deposit, and a fraction of the sediment was transferred back to it which ages before had been swept westward from its uplands and mountain ranges. But not only were the regions of erosion and sedimentation reversed; the physiographic conditions were also different. In the late Mesozoic a gentle and limited subsidence due to tilting of the continental margin permitted fluviatile outbuilding, but the subaerial delta plain faced the powerful waves of a deep and wide ocean. In the Paleozoic by contrast it was the sinking bottom of the geosyncline which gave the rivers tasks of infilling which they were usually unable to accomplish; but the action of the interior sea was relatively weak, for its waters were shallow, shifting, and at times drained away by slight continental movements.

Thus in the late Mesozoic the outbuilding of the rivers was opposed by powerful marine planation which at last gained the mastery. In the Paleozoic they contested rather against a zone of downsinking which crossed their paths. The character of the sedimentary formations of the two eras was controlled by these different geologic conditions. In the Mesozoic there developed a wide but thin mantle of detrital deposits, of which a broad outer part must always have been marine. In the Paleozoic the clastic sediments formed deposits more remarkable for great and variable thickness than for width, and the proportion of marine beds was determined by the varying rates of subsidence and erosion. The conditions for river work during the Paleozoic were more highly variable and gave rise to greater extremes than during the following era. When uplift of Appalachia and resulting erosion were the dominant features the interior sea may have been largely or wholly displaced. At other times, when Appalachia had been worn low and could not supply its rivers with abundant land waste, slight regional subsidence brought the sea eastward over the geosyncline and against the eroded mountain base.

Where rivers maintain a land surface against a sea, delta conditions are implied. In the case of the Upper Jurassic and Lower Cretaceous deposits the landward margin of the subaerial beds has been eroded and the corresponding seaward or subaqueous beds are concealed to the southeast. Erosion exposes at the present time only a certain belt of the ancient deltas, and the conception of the whole has to be supplied by deduction from the principles of sedimentation. In the case of the Appalachian geosyncline the portions of the sediments which are preserved instead of thinning out against the old land are seen to diminish in

thickness away from it—that is, the maximum thicknesses of the Paleozoic clastic formations are commonly seen in their easternmost outcrops in the Great Valley—those outcrops nearest the old land from which the sediments were derived. This means that they are now eroded from the whole eastern part of the original geosyncline. Instead of restoring the boundaries of the Paleozoic uplands at the present limit of the pre-Paleozoic rocks, this zone of the Appalachian Mountains and the Piedmont Plateau are to be looked on rather as the eastern side of the ancient geosyncline and bordering a broad land farther to the east. At times this intermediate belt was overflowed by the sea; at times it was subject to folding, uplift, and erosion; but at other times it was a Piedmont plain, the seat of river aggradation. In the Paleozoic Appalachian geosyncline, unlike the late Mesozoic coastal formations, it is the seaward and not the landward half in which the section has been preserved. But exactly as the late Mesozoic fluviatile deposits imply a seaward phase farther from the land, so in the Paleozoic the dominantly marine character of thick sand and mud formations deposited in shallow water imply the former existence of the fluviatile beds of deltas on the landward side. At times the delta conditions doubtless disappeared owing to low relief of the lands and the widespread seas planing inland against its shores. At other times the delta conditions disappeared because of the entire retreat of the sea; but much of the time they were present, and in the Upper Paleozoic, when clastic sedimentation became more dominant, the subaerial beds extended into the western half of the geosyncline and their outer portions are therefore still preserved, interfingering with marine beds farther to the southwest.

For a complete conception of ancient conditions the imagination must restore to a sedimentary system those parts which are destroyed as well as those which are buried, and not invest them merely with the characters exhibited by the visible portion, but rather ascribe those characters which would pertain to them as the several members of an organic whole.

The borders of the Appalachians have been used as an example of the varying development of delta conditions. But other uplands bordered by geosynclines or facing slightly submerged parts of the continental platforms have supplied similar physiographic settings. To simply determine in such regions some formations as fluviatile and others as marine does not complete the conceptions of the larger relations of each to the other, which is given by the theory of the growth and retreat of deltas.

When such a conception is attained, the mind may look back at the completed geosyncline and view it as made of beds laid down on the one

side by the land and on the other by the sea, each advancing into the other and dovetailing in intricate fashion, though one or the other may much of the time be absent, and when present seldom of equal development. Looking down through the depths of the solid rocks the surface of separation is seen to be generated by the ascent of the strand-line through the geologic ages, oscillating back and forth and often completely across the zone of sedimentation.

From the historic aspect the process of sedimentary infilling may be viewed as the record of a contest between land and sea. The strand-line separates the territory of the opposing forces—Poseidon, the god of the ocean, warring against the earth-born Titans. For a time the field may be held by each; the contest oscillates back and forth, recorded by delta conditions. Then, owing to an advantage gained by the sea, the strand-line may be pushed far inland and victory rests with Poseidon. But at other times the strand is driven back to the margin of the continent, the Titans in their turn are temporary victors, and the lord of ocean is compelled to rule within his proper realm.

Part II.—Evaluation of stratigraphic Criteria

COMPLEXITY OF THE PROBLEM

The strata of ancient deltas are now exposed for study as a consequence of uplift and partial erosion, and the broader concepts in regard to their original nature are derived from a synthesis of the observations on individual outcrops. Increase of knowledge rests on an accurate interpretation of the conditions of origin of the strata as seen in these outcrops. But, as noted in the introduction, it is the strand-line which separates the two widely contrasted zones of life, and the most fundamental use of criteria is therefore to distinguish deposits accumulated on the land surface, either by wind or water, from those originating under permanent bodies of water. As applied to deltas the initial problem is in consequence to determine the distinctive stratigraphic characters of the subaerial plain as contrasted to all the other parts of the delta, but especially to the rather closely related subaqueous portion of the topset plain. In order to prevent undue reliance from being placed on indeterminate criteria it is necessary to discuss the degree to which they may occur in various situations and to find if possible in such cases minor distinctions which may be of determinative value. In general it may be remarked that considerable caution must be used in drawing distinctions between water-made structures of the land and sea. Evidences of exposure to the air, on the other hand, as shown by special structures or by fossils, are inherently of higher value.

Beyond the initial problem of the separation of the subaerial from the subaqueous portions, however, many subsidiary problems arise. The very complexity of chemical composition, of structure, and of fossil content make possible by their variations and combinations a highly significant geologic record. The stratigraphic characters of land deposits especially bear the impress of climate and topography. The subaqueous deposits are related in their nature to life, depth of water, temperature, salinity, tide, and currents. According to the quality of this evidence will rest the conclusions as to the marine, estuarine, or lacustrine nature of the deposition.

It is evident that many criteria are subject to gradations in nature and in clearness of development, and in the following discussion of stratigraphic characters the method will be to pass from those of less to those of greater determinative value.

ABSENCE OF FOSSILS

This is a purely negative criterion, which by itself is of little value in distinguishing between subaqueous and fluviatile terrestrial deposits. The absence of molluscan life over considerable tracts of shallow sea bottom has been pointed out recently by Kindle.[13] Even if life of some sort has existed there are processes of abrasion and solution which may destroy all evidences of it on the shallow sea bottom as well as on the land. Oxidizing decay and solution are normally more effective in land deposits, owing to the circulation of air and ground water; but mechanical destruction, through movements of surface materials, is more broadly effective on a wave-worked bottom. The limestone muds of coral beaches show how effectively a mass which originally was entirely composed of organic remains may by abrasion, solution, and redeposition come to be almost barren of fossils. As a result of these agencies, unfavorable to life or destructive to its remains, sandstones of either continental or marine origin are the formations most apt to be without fossils.

Examples of such sand deposits accepted as continental may be cited in the Triassic sandstones of both east and west and the sandstone members in the Tertiary of the Rocky Mountain region. Casts of tree trunks or silicified wood may reward careful search and calcareous phases tend to protect animal skeletons from solution. But considering the abundance of the past life which was associated with the deposition and the enormous dominance of unfossiliferous beds, it is seen how accidental is the preservation of fossils. Of marine sandstones, barren examples may be

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[13] E. M. Kindle: Cross-bedding and absence of fossils considered as criteria of continental deposits. American Journal of Science, vol. xxxii, 1911, pp. 225-230.

cited in the beds which commonly underlie the Cambro-Ordovician limestones; also of many Upper Paleozoic sandstones, which because of association with fossiliferous beds and distance from the sources of erosion imply a marine origin.

In mudstones of continental origin absence of fossils is especially associated with red beds, implying a completeness of oxidation and solution. Carbonaceous shales of land origin if of post-Silurian date commonly preserve some plant remains. In marine beds, however, carbonaceous shales are not so favorable to the existence of fossils, apparently owing to the absence of plants with fibro-vascular tissues and of stagnant bottom conditions. Calcareous shales of continental origin are more apt to be barren of fossils than marine shales of the same composition.

Skillful search and the accident of exposure have resulted, however, so frequently in finding rare fossils or special kinds of fossils associated with apparently barren formations that absence of fossils in connection with the kind of beds should be used merely as a criterion suggestive and not conclusive of the mode of origin.

COLOR OF SEDIMENTS AND THE RELATIVE INFLUENCE OF LOCATION AND CLIMATE THEREON

Sediment carried by rivers is subjected to oxidation both while in transit and after deposition on the surface of the floodplain, until its burial by overlying layers carries a stratum below the level of ground water. Where the ground water level is coincident with or higher than the surface, organic matter accumulates and deoxidizing processes take place. A certain fraction of delta deposits, depending on the proportion of back swamps and coastal swamps, therefore show colors ranging from green to blue, according to the state of the iron oxide, and from white through gray to black, according to the amount of carbon. But over the larger portion of the delta the iron of the soil is more or less completely oxidized during the seasons of dryness, and the corresponding colors—yellow, orange, red, or brown—are in evidence. The ratio of these oxidized and deoxidized sediments varies with the flatness of the delta and the character of the climate. Color is therefore in itself no criterion by which to distinguish between terrestrial and subaqueous deposition, but yellows, reds, and browns are the dominating colors of continental deposits save in certain geological periods. A red shale which grades laterally into a green, gray, or black shale gives therefore strong indications of terrestrial origin for the red portion. Such a relation is found in the Wamsutta Red Beds of the Rhode Island basin. The other portions may be swamp deposits of deltas or, so far as the color goes, of subaqueous origin. This evidence from red beds is especially strong when found in

formations which are dominantly black, as in coal formations, but unless the transition can be traced is not a positive indication; as seen, for example, in the Lower Barren Coal Measures, where at Pittsburg a marine fauna may be observed in a limestone band 2 to 3 feet thick, resting on red shale and succeeded by 1 foot of black shale, passing again into red shale.[14] The evidence thus shows a time of red shale deposition, of possible marine origin, intervening in the Pennsylvanian when even the land muds gave normally a black shale formation. Taking the contrary case, lenses of gray or black shale in a formation which is dominantly red, such as the black shale bands in the Triassic rocks of Connecticut, is a suggestive though not positive indication as to the subaqueous accumulation of the dark bands, perhaps as swamp deposits if black; as lacustrine deposits if gray or olive in tone and associated with thin and regular bedding.

With respect to very early geological times, such as the Keewatin and Huronian, the absence of red is of doubtful significance, owing to the unknown composition of the air of those early periods and its possible ineffectiveness as an oxidizing agent.

Turning to the sea deposits, the dominant color of bottom muds at the present time, omitting the abyssal red clays, is seen to be blue or gray to black. There are, however, relatively small areas of red muds off the shores of certain tropical lands. In other localities, as the Red Sea, yellow muds occur. The dominance of blue muds corresponds with the known deoxidizing influences of the sea bottom, but at other times the oxidizing conditions which now give local areas of red muds may have been widely prevalent. Consequently in other geologic periods the dominant color effect may be reversed. In the Pennsylvanian, for example, the bulk of both terrestrial and subaqueous shales are dark with carbon. In the Clinton formation, on the contrary, the deposits of the shallow sea are brilliant with ferric oxide.

The influence of climate and the kinds of bacterial or inorganic reactions which it favors is therefore a factor of stronger control than conditions of continental or marine deposition. It is only in mean climatic states, such as the present, that the place of deposition exerts a dominating influence on color.

Special examples of complex color relations are discussed in the following topics.

VARIEGATED FORMATIONS

Green shales and red sandstones—Recent example, the basin of eastern Persia.—Variegated formations offer special problems which may be

[14] Seen in the "brilliant cut off" of the Pennsylvania Railroad at East Liberty.

divided into several cases. First are those variegated beds, consisting of clays intercalated with silts or argillaceous and ferruginous sands, in which the clays show an absence of ferric oxide as contrasted to its presence in the other strata. Such a formation, now in process of origination, has been studied by Huntington in the delta of the Helmund and the lake of Seistan, of eastern Persia. The latter is a shallow and variable water body in the center of the waste-filled basin. The margins of the lake support a dense growth of reeds and the bottom deposits consist of a fine greenish or white clay. Over the subaerial plain the deposits range from a silt near the head of the delta to a more clayey nature near the lake. The upper parts of the delta are well drained and the soil well aerated. Over these areas light brown is the dominating color. The flat swampy clay land near the lake may have been partly deposited as lake beds and are now through considerable periods of time overflowed or at least saturated with water. In these places the browns fade out and light-colored soils with black areas prevail.[15] The relation of the present surface deposits to the past accumulations are well shown where part of the lake bottom has been uplifted by recent volcanic action and erosion has exposed the sequence of beds. From these Huntington has interpreted the Pleistocene history. The significant feature from the present standpoint is that the fine sands and silts are in nearly all cases pink or brown, representing former fluviatile deposition, and the lower beds show more intense pink and reds. This transition in color from the recent to the ancient deposits is to be attributed to the ready partial dehydration which limonite undergoes with time, warmth, and pressure. The clay bands which recur frequently through the section, though in part pink, hold many green members. As shown by the present conditions, the green clays mark the presence of former lacustrine conditions and point to the significance of clay bands of these colors in red silts or sandstones of other formations.

Although the climate is arid and the lake occasionally dries up, saline deposits are absent, since the lake when at high level overflows into a lower basin. In general, however, saline deposits would be associated with sedimentation under the climatic conditions which prevail in Persia, and deoxidation of lacustrine deposits would be less effective.

Ancient example, the Orcadie basin of Scotland.—An example of the application of these color relations to an ancient deposit may be made as follows: In the Lower Old Red Sandstone formations of the Orcadie basin of Scotland the sandstones and non-calcareous shales are domi-

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[15] The basin of eastern Persia and Seistan. Carnegie Institution Publication, No. 26, 1905. (Also personal communication.)

nantly red, but some 10,000 feet of the middle part of the series are characterized by flagstones and shales, with more or less calcareous matter. Gray, green, and blue are prevailing colors in these, but no marine fossil is known and mud cracks are remarkably developed. These beds, therefore, represent the lower, poorly drained parts of an interior fresh-water basin which was, however, dried out at repeated intervals. The absence of saline deposits in these playa beds indicates that outflow took place at times of high water, and the climate would seem, therefore, to have been characterized by an alternation of dry and rainy seasons rather than by a truly arid condition, such as has been conceived by certain British and Scotch geologists. This interpretation differs from those commonly offered in that the basin is here thought to have consisted of fluviatile plains and playa lakes rather than a great basin lake, under whose waters all the sediments were deposited.

Red shales and green sandstones—Subrecent example, the Siwalik formation of India.—The second case of variegated beds consists of color relations the reverse of those just considered. In place of deoxidized shales and oxidized sandstones there are formations in which the shales are oxidized and are interbedded with deoxidized argillaceous sandstones. An example of such shales and sandstones which have accumulated under conditions concerning which there is general agreement may be cited in the Siwalik formations of the sub-Himalayas. These are Neocene deposits upward of 15,000 feet in thickness skirting the southern side of the Himalayas. They were laid down as fluviatile outwash from the rising mountains and have become exposed through being themselves upturned and eroded in the latest movements. Medlicott and Blanford describe the Siwalik formations as follows:[16]

"Sandstone immensely preponderates in the sub-Himalayan deposits, and is of a very persistent type from end to end of the region and from top to bottom of the series. Its commonest form is undistinguishable from the rock of corresponding age known as Molasse in the Alps, of a clear pepper and salt gray, sharp and fine in grain, generally soft, and in very massive beds. The whole Middle and Lower Siwaliks are formed of this rock, with occasional thick beds of red clay and very rare thin, discontinuous bands and nodules of earthy limestone, the sandstone itself being sometimes calcareous and thus cemented into hard nodular masses. In the Sirmur group (below the Siwalik group) generally, and locally in the Lower Siwaliks, the sandstone is thoroughly indurated and often of a purple tint, while retaining the distinctive aspect. In the Upper Siwaliks conglomerates prevail largely; they are often made up of the coarsest shingle, precisely like that in the beds of the great Himalayan torrents. Brown clays occur often with the conglomerate, and sometimes

[16] Manual of the Geology of India, part II, 1879, pp. 524-526.

almost entirely replace it. This clay, even when tilted to the vertical, is undistinguishable in hand specimens from that of the recent plains deposit; and no doubt it was formed in a similar manner, as alluvium. The sandstone, too, of this zone is exactly like the sand forming the banks of the great rivers, but in a more or less consolidated condition. Thus it was suggestive, and not altogether misleading, to say that the Siwaliks were formed of an upraised portion of the plains of India.

"The fresh-water origin of the Siwalik formation seems almost as indisputable as the marine origin of the Subathu beds; yet, until lately (1879), it has been usual to consider the Siwaliks marine. The notion was probably a relic of the opinion that a water basin was an essential condition of the extensive accumulation of deposits, and that a sea margin would be required for such a great spread of shingle as that of the Siwalik conglomerates. The same opinion, on the same grounds, has been extended to the plains deposits themselves.

"The continued experience that the fossil remains in these Tertiary strata are exclusively of land or fresh-water organisms, made this view untenable; and in time it came to be realized that the deposits themselves bear out the same opinion; the mountain torrents are now in many cases engaged in laying down great banks of shingle at the margin of the plains, just like the Siwalik conglomerates; and the thick sandstones and sandy clays of the Tertiary series are of just the same type of form and composition as the actual deposits of the great rivers.

"Beds of this character alternate with the upper beds of the Subathu group; so it seems probable that from early Tertiary times the sea has been excluded from the sub-Himalayan region, and that the whole of the sub-Himalayan deposits, above the Subathu group, are fresh-water and fluviatile, and formed on the surface of the land. They are in fact subaerial formations, like the river alluvium and bhabar deposits of the present day."

Speaking of these formations as they occur in the Salt Range in the Punjáb, Wynne makes the following statements:[17]

"Everywhere from one end of the range to the other, and always on its northern and eastern aspects, the uppermost rocks of the Salt Range series are innumerable alternations of gray or greenish sandstones, of not great hardness, with red or light-brownish orange clays, more rarely with conglomerates, but frequently with harder fine-grained sandy beds of peculiar concretionary pseudo-conglomeratic structure. . . . The alternating bands of sandstone and clay are from seventy to a hundred and twenty feet in thickness, being very frequently about a hundred feet each, but some zones are much thicker."

It is the Middle Siwalik which especially shows the association of gray or green sandstones and red clays. All parts contain the bones of mammals and fresh-water reptiles. It is seen from this description that such combinations of red clays and gray or green sandstones are features of fluviatile deposition under certain intermediate climatic conditions. The

[17] Memoirs of the Geological Survey of India, vol. xiv, 1878, p. 108.

contrary case, however, still remains to be shown,—that other examples of such red shales and green sandstones may not be marine. Fortunately, an illustration from the Devonian of eastern North America shows that this combination of colors is there approximately restricted to an ancient terrestrial formation and the colors become more uniform and show a greater deoxidation where the deposit becomes clearly marine. Marine action, therefore, tends to eliminate these variegated color relations. The details are as follows:

Ancient example, the Catskill formation.—The Catskill formation of New York and Pennsylvania consists typically of thick members of poorly laminated red shales interbedded with olive green or gray sandstones. Some reddish argillaceous sandstones also occur. In the Catskill Mountains of southeastern New York the formation has a thickness of 3,000 feet and thickens to twice that amount farther southwest in Pennsylvania. In the eastern outcrops it represents the whole of the Upper Devonian, but in passing west the Catskill is seen to overlap on the Chemung, and only the uppermost Catskill occurs in western New York and Pennsylvania. The Catskill and Chemung occupy the same time interval, but represent landward and seaward facies in the sedimentation, the Catskill conditions gradually advancing westward . This formation is very poor in fossils, and such as occur are partly if not wholly of fresh or brackish water forms. In the Chemung grays and olive greens are the dominating colors of the whole formation, shales and sandstones alike, and marine faunas occur at many horizons. The variegated coloring of the Catskill is thus seen to be correlated with the absence of marine fossils and to disappear in this case where marine conditions clearly prevail. The indications of mode of origin which have been published hitherto are, however, mostly of indeterminate value, the chief one being that regarding the contrast to the marine Chemung, which has just been pointed out. The writer has, however, studied closely a number of sections from the Hudson to the Potomac River and has found scattered proofs of subaerial exposure at the time of accumulation. These are to be observed, however, only under exceptionally favorable conditions, and it is clear from this that they imply a far wider existence of subærial conditions. It is not the place here to describe these evidences nor to discuss the problem of the Catskill in detail, but it is to be noted that mud cracks and root-marks were found near Cumberland, Maryland, extending through about 120 feet of strata close to the base of the Catskill. On the Schuylkill River is exposed the southeasternmost outcrop of the Catskill of the Appalachian geosyncline. This is the outcrop which lies nearest to the sources of the sediment, but that it was some

distance from the margin of the original formation is shown by the enormous thickness which the Catskill has here. Well defined mud cracks and rainprints were found ranging through about 100 feet of beds and lying about 1,000 to 1,200 feet above the base of the formation—that is, in its lower part. The upper part shows a thick series of transition beds, largely sandstones with some red shales, grading into the Pocono sandstone. In these red shales mud cracks were found ranging through a thickness of 1,200 feet of beds and thereby showing characteristic exposure of the clays to drying in the air. More doubtful evidences of subaerial exposure were found in other parts of the section. The Catskill formation may then be tentatively regarded as of truly fluviatile and terrestrial origin. The climatic conditions were intermediate between the aridity of the Upper Mississippian period, which resulted in salt and gypsum deposits, and the moister Pennsylvanian giving rise to coal measures. Either extreme offers the conditions for a good record of subaerial exposure; in the first case by means of mud-cracked shales; in the second by means of vegetation preserved *in situ*. The intermediate condition shown by the Catskill deposits prevents a good record of either sort, but is marked by the variegation in colors—fully oxidized floodplain clays alternating with deoxidized sands.

Such a relation of red shales and gray or green sandstones may then be taken as presumptive evidence of subaerial river deposition. It should not, however, be taken by itself as positive evidence, as the number of cases studied on which the conclusion rests is still somewhat limited.

Lateral and vertical variegations in clays.—The third case of variegated beds consists of those in which a great variety of colors are found and in which the colors are variable along the stratum. Such variations and mottlings are especially developed in the late Mesozoic formations of the Potomac group, discussed as an illustration of the delta cycle, and are especially suggestive of the local variations of soil drainage which are found on the terrestrial surface of certain deltas. Where the ratio of flowing water to transported sediment is large and the sediment is carried chiefly in suspension the grade of the lower part of a river may be very low, in many cases but a few inches per mile. The local inequalities of the floodplain determine the presence of lakes, swamps, or dry land. A forest cover in such a region supplies organic acids and favors partial leaching and concentration of the iron and leads to development of such high contrasts in coloration. The far greater uniformity which prevails at the bottom of permanent water bodies does not favor this effect. Other reasons were shown for regarding the Potomac group as consisting of delta formations. Such variegated beds are then highly

suggestive of terrestrial deposition, and indicate, furthermore, a large development of swamp and pond conditions under a normally humid climatic condition.

Regular banding in mudstones—A climatic record in bottomset beds.—The fourth case of variegated beds consists of uniform fine-grained shales in which the strata show marked variations in color. Bedding may be practically absent save as marked by color. The variations are due either to changes in the carbon content, low carbon being apt to be associated with more siliceous bands, or changes in the state of the iron oxide, green and red bands making up the rock. Such variations are best observed in slates which cleave across the bedding and thereby show the latter as bands of darker and lighter colors. The material was originally clay, which settled slowly from suspension on a bottom presumably not affected by waves. They are typically marine deposits, and the rhythmic character of the alternation may be due to changes in currents or in the shifting of river mouths, but the regularity of the recurrence in many instances and its dependence on a varying state of oxidation is suggestive of a climatic rather than a geographic cause. In bottomset beds such a climatic rhythm may be expected to record itself by a variation in color. In open seas the alternation is marked more commonly by a change in the proportions of shale and limestone. The rhythm is usually from a few inches to a few feet in thickness, and such oscillations are of rather characteristic occurrence in shaly limestones through geological time. They are to be sharply separated in significance from those variegations related to the physiographic controls of shifting channels and swamps in delta and floodplain deposition. If a climatic origin for such regular banding shall become definitely established the phenomenon is of high interest, for in that case there is seen to exist a detailed though fragmentary record of short period climatic fluctuations running back through the geologic ages and indicating that oscillations about the average for the place and time are and always have been characteristic features of terrestrial climates. Such rhythmic changes of shorter and longer periods are indeed suggested by the behavior of modern glaciers and the retreatal moraines left by the extinct ice-sheets of the Pleistocene.

A striking example of such red and green rhythmic color banding in slates has been recently studied by Dr. D. D. Cairnes, of the Canadian Geological Survey, who has kindly furnished the following description of them for incorporation into this paper:

Banded slates of the Orange group, by D. D. Cairnes.[18]—These red and green banded slates or metamorphosed mudstones are included in a group of sediments provisionally named the Orange group, which is at least 6,000 feet in thickness and occurs extensively along that portion of the 141st meridian (the Alaska-Yukon international boundary) between latitudes 66°00 and 67°00, which was geologically studied and mapped by the writer[19] during the past season (1911). Terranes that probably correspond to, and that at least closely resemble this group both lithologically and stratigraphically, also occur on the Upper Macmillan and Upper Stewart rivers and have been briefly described by both McConnell and Keele.[20] Triassic fossils were found by Keele in slates underlying the banded mudstones in the Upper Stewart River region; and a considerable number of imperfect invertebrate remains were collected by the writer along the 141st meridian from the lowest beds of the Orange group, and these remains have been identified by Dr. T. W. Stanton as being of Mesozoic and in his opinion probably of Cretaceous age.

On account of the somewhat highly altered character of these Orange beds and the general scarcity of their outcrops, no complete section of the group has been obtained at any one point, and the lithological characters of the members composing it vary considerably throughout the areas in which they have been identified. At one point banded slates 200 to 250 feet in thickness occur, occupying a central position in the Orange group; these pass downward into dark gray to black slates and phyllites and are overlain by greenish gray sandy shales. Approximately 25 miles farther north, however, the banded slates are at least 1,800 feet in thickness; there they directly overlie Silurian limestones and dolomites and are in turn overlain by black slates. In no place was any gradation noted from the red and green banded mudstones to other beds, the change being invariably abrupt.

The color bands range from those that are scarcely perceptible to others several feet in thickness, and in places either the red or the green persists for 50 to 100 feet or even more to the complete exclusion of the other color. In general, however, the bands are from one-fourth to 2 inches in thickness, and throughout several hundred feet of beds the

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[18] By permission of the Director of the Geol. Surv. Branch, Dept. of Mines, Canada.

[19] D. D. Cairnes: Summary Rept. Geol. Surv., Dept. of Mines, Canada, 1911 (in preparation).

[20] R. G. McConnell: "The Macmillan River, Yukon district." Ann. Rept. Geol. Surv. of Canada, vol. xv, pp. 31A-34A.

J. Keele: "The Upper Stewart River region, Yukon." Ann. Rept. Geol. Surv. of Canada, vol. xvi, pp. 13C-18C.

J. Keele: "A reconnaissance across Mackenzie Mountains on the Pelly, Ross, and Gravel rivers, Yukon and Northwest territories." Geol. Surv., Dept. of Mines, Canada, No. 1097, 1910, pp. 33-36, 39-40.

color rhythm is remarkably regular, but in other places numerous fine, delicate, and even hairlike green bands are distributed at very irregular intervals throughout red beds. Everywhere the individual bands are strikingly persistent.

At one point a number of dolomite beds were noted to occur intercalated in the banded mudstone series, and throughout a thickness of 50 feet the formation consists of alternating slates and dolomites, the dolomite bands ranging in thickness from one-fourth of an inch to about 2 feet, and the slate bands from one-eighth of an inch to several feet in thickness.

RELATIONS OF BEDDING TO MODE OF SEDIMENTATION

Method of presentation.—The preferred method of science is induction, the accumulation of such a variety of observations, covering all the possible cases of occurrence, that from their classification the laws which control the phenomena may be determined; but induction is unsafe if based on partial observations. Where the principles which control the operations of nature are better known than their results, deductive reasoning, on the contrary, is the safer guide to conclusions, but is a method which needs to be checked as much as possible by appeals to observation.

For a study and comparison of the characteristics of bedding as contrasted in the deposits of the subaerial and subaqueous plain, the inductive method calls for observations to be made on modern sediments of the two regions now in process of deposition, and on ancient sediments, whose conditions of origin are known from other criteria. Such observations are, however, as yet so insufficient in variety and usually so qualitative in character as to be unsafe when used alone for the inductive determination of distinctive criteria. For example, cross-bedding is known to occur in both fluviatile and marine deposits and no convincing distinctions have been drawn between the two by an observer who has fully studied both. This section of the subject, therefore, can best be treated deductively, drawing the distinctions which should result from the principles which control wave and current action and checking the conclusions as far as possible by citation of the known facts of stratigraphy.

Lamination of mudstones—Effects of subsidence from suspension.—Lake or estuarine clays, if deposited below the depth affected by waves and currents, are characterized by a very regular lamination which is commonly closely spaced and may give rise to paper shales. The materials are wholly derived from suspension in water and are not marked by the intercalation of sand lenses. The same is true of marine mudstones, but the more powerful waves of the open seas are able to affect a greater depth of water and restrict to such depths the areas free from

wave action. The preservation of perfect and fine-grained lamination in many ancient fossiliferous marine muds seems to show that the muddy ooze of deeper waters is not stirred by the bottom life to the same extent as is true within similar sediments on the land. The smothering nature of the deep, soft ooze is in fact unfavorable to most kinds of invertebrate bottom life and may be correlated with the sparingly fossiliferous character of thinly laminated non-calcareous marine shales.

Effects of waves.—Where muddy sediment is supplied to shallow waters, as off the mouth of the Mississippi, the coast charts show intermixtures of sand and mud, some parts of the bottom soft and others hard. The waves of storms stir up such bottoms and shift its materials. The water becomes discolored with sediment and considerable thicknesses must settle on the subsidence of wave action. The stratigraphic result to be anticipated is a destruction of the fine and regular lamination of clays and their intermixture with sand and silt. Such a massive structure in clays is observed in certain fossiliferous marine formations—such, for example, as the Merchantville clay of the Upper Cretaceous of the Atlantic Coastal Plain, where bedding is characteristically absent except in the presence of laminæ of sand. Where two materials of unlike nature, such as clay and sand, are both present the results are quite different than in mud deposits alone.

Effects of subaerial actions.—On floodplains extensive pelitic deposits are laid down in backwaters but little affected by currents, in shallow lakes, and on the frontal parts of the delta. Where such clays are exposed to the air various agencies tend to destroy the original lamination. The effects of earthworms and roots are well known, but over regions where the clays become mud-cracked a still more effective agency is in operation. The cracks break across the bedding and in thick clays may extend to depths of some feet. The next flood waters sweep more sediment into these cracks, the edges of the polygons slack and crumble and the cracks become obliterated. The following period of drying opens them again, but on more or less independent patterns. Thus the clay is subjected to a thorough vertical mixing through a period of time required for an accumulation equal to the depth of the mud cracks. Where the character of the sediment remains uniform, the filling is of the same material as the dried polygons and there results massive clay formations. in which both lamination and the evidence of mud cracking are absent. The latter are commonly revealed only when sand or sandy clay has been swept over the mud-cracked stratum, filling the cracks and protecting the stratum from further action. It is consequently the bottom of sandy strata resting on beds of shale which most commonly show the pattern

of the mud cracks. This poorly laminated bedding is especially characteristic of the thick red shale members of the Catskill formation, which there is reason to believe is largely fluviatile and contrasts with the better lamination in the olive shales of the Chemung which represent the offshore deposition.

Thus, to sum up the previous discussion, it is seen that highly perfect lamination in pure pelites is characteristic of quiet subaqueous deposition, but an absence of such lamination is no proof of subaerial conditions, though most extensively developed in such situations. It is to be noted, however, that studies on the character of lamination in modern sedimentation is a subject which has received but little attention.

Stratification of sandstones—Effects of waves.—The transporting agencies of marine sands are primarily waves, secondarily currents. In fluviatile work, on the contrary, currents are the controlling agency and the work of waves is limited. In neither region, however, is either one entirely absent and locally the minor activity may dominate the resulting structure.

Normal wave action tends to sweep sand in a direction opposite to that of the surface wave motion,[21] but where the bottom shallows the wave becomes to some degree a wave of translation and carries the coarser bottom material which it can move with the water toward the shore and results in the building of bars. Waves over a broad bottom which is flat tend therefore to maintain an even depth of water and develop a regular bedding, the sand being swept under normal wave action from the slightly higher places to the quieter water of greater depth. The differing direction and force of storm winds tends also to shift the bottom materials. The action near the shore is different in character from that on the flat offshore bottom, since the material tends to be moved partly to deeper water, partly to shallower water, and the shoreward slopes are steepened, the outer slopes flattened. The shifting of bars results, further, in a continual cutting out and redeposition elsewhere of the sand beds. This is well illustrated off the New Jersey and Maryland coasts, irregularities of the bottom extending to depths of 10 fathoms at distances up to 15 or more miles from the coast.

It is important, however, that a quantitative estimate of such effects be given, and a study of the coast charts shows that the maximum slopes of the submerged sand banks off the open coasts, where waves and not currents are the controlling forces, is not over 15 feet in 1,000. Where

[21] N. M. Fenneman: Development of the profile of equilibrium of the subaqueous shore terrace. Journal of Geology, vol. 10, 1902, pp. 1-32.

the bottom profile is in better adjustment to the waves the inequalities are much less. For example, south of Long Island the bottom profile deepens smoothly to 30 fathoms and beyond. In small bays free from tidal races the same smoothness of bottom is noted, but in much shallower water. It is seen, therefore, that sharp channeling and flow and plunge structures are not features of wave action, but of current action, and tend to be smoothed out in open-water bodies. Although the profiles of sand beds on the subaqueous plain tend to be smoother in detail than those of the subaerial plain and of gentler slope, there are, nevertheless, decided inequalities over larger distances. The sediments are dominantly swept in certain directions and concentrated bottom currents are thought to prevent deposition in others. Such effects are not, however, to be studied from the shores. The conspicuous effects of an ocean surf on the shore impress the imagination, but have little direct relation to the making of sedimentary structures on the floor of the water body. Where waves drag on a shallowing bottom and throw up bars a cross-section of the resulting bedding would show sandstone lenses whose upper surface is convex upward with gentle slopes and cross-bedded structure. Channeling by currents, on the contrary, cuts into the beds below and undercuts the sides, giving curves which are convex downward. Currents also build shifting bars with convex upper surfaces in places of slack water. The slopes of channels and river bars are, however, steeper and the deposits in the slack water are more local and irregular.

It is one of the important principles of sedimentation that the beds of sand which are laid down, and not later disturbed, are the results of the heaviest storms. These churn up the shallower bottom, loading the water with sediment and moving part of it to a greater depth of water whither minor storm waves can not transport the sand. Here the sand is laid down gently and without indication of the commotion which is reigning elsewhere. A sandstone bed may thus be deposited during a single storm and give the appearance of rapid sedimentation, when in reality years may elapse between the deposition of successive coarse beds. During such storms, although the sand is worked out to unusual depths, the silt of those depths has also been greatly stirred and is in part worked farther seaward, in part settles back in place. The resulting bed from a single storm, owing to this stirring, will show a sharply defined surface to the sand, frequently ripple-marked, witness to the culmination of the storm, on which another bed of mud or silt will come to rest and record the following period of lessened wave action. This is normal flagstone bedding.

The most striking effect of waves is in the production of ripple-mark[22] as distinguished from current-mark. The size of the ripples is some function of the wave length, but the relation is not a simple one, and it is not possible at present to determine from the ripples the depth of water in which they were made. It is known, however, that ripple-marks may occur in depths of several hundred feet of water,[23] and it may be produced by broad smooth currents of water affecting the bottom below wave base, and which by their evenness and breadth of movement may prevent the lack of symmetry which is especially characteristic of current-mark as contrasted to ripple-mark. The regularity of ripple-mark produced by wind action illustrates the possibility of currents simulating the effects of waves. River currents, however, tend to prevent regularity of bedding and symmetry of ripple-mark. It appears, therefore, that typical water-made ripple-mark associated with regularity of bedding in sandstones is especially associated with the subaqueous plain of deltas and the bottoms of shallow seas. It is developed, however, to a limited extent also over the subaerial portions of deltas, where shallow waters unaffected by strong currents have stood for a time before being drained away. Consequently it is not the presence of ripple-mark, but its dominance and association with other features which suggests offshore deposition.

The question may now be raised as to the types of cross-bedded structure which marine action will impose on a sand formation. Experience shows that many marine sandstones show cross-bedding on a moderate scale, and even limestones are known to exhibit in some instances the same structure. Kindle has recently called special attention to this feature.[24] Gilbert, furthermore, has studied the type of cross-bedding which may result from the superposition of successive beds of ripple-marked sand, and has described the giant ripple-marks of the Medina sandstone in western New York.[25] Gilbert puts forth, merely as a suggestion, the hypothesis that these giant ripples may imply correspondingly enormous waves in the Medina Sea. The explanation should, however, be sought apparently in some other direction, since ocean waves of the present time are not observed to construct true ripple-mark on this scale, and the general evidence of the shallowness of the epicontinental seas, and especially of those with sandy bottoms, would seem to preclude

[22] For a paper which gives the bibliography in addition to later observations, see Cornish, Vaughan, On the formation of sand-dunes. The Geographical Journal, vol. ix, 1897, p. 278.

[23] Sir A. Geikie: Text-book of Geology, 4th edition, 1903, p. 562.

[24] American Journal of Science, September, 1911, pp. 225-227.

[25] Ripple-marks and cross-bedding. Bull. Geol. Soc. America, vol. 10, 1899, pp. 135-140.

definitely waves even as great as those of the present open oceans. The explanation should rather be sought in some nodal effect, or the dragging, partial breaking, and recovery of waves of translation in very shallow water, or perhaps some relations of waves to undertow currents. Whatever the explanation may be the fact remains, however, that such structures are presumably formed on the subaqueous plain, and their migration across a bottom on which sand was accumulating could give rise to a moderate degree of cross-bedding, but one presumably distinct from the steeper and more irregular cross-bedding due to current action where the latter becomes a dominating action.

If cross-bedding in a sandstone or limestone, presumably marine, occurs on a large scale it is possible that it may be due to wind action on material abandoned by the sea or blown inland. Grabau has called attention to an instance on the shores of the Red Sea where an eolian limestone of foraminiferal tests is accumulating many miles inland,[26] and the eolian limestones of Bermuda blown inland from beach materials are well known. Such cooperation of wave and wind action is favored in shallow waters and makes more uncertain the direct interpretation of ancient formations and calls for a closer study of modern sedimentation under analogous conditions.

Effects of currents.—Currents as carrying and depositing agents are especially characteristic of fluviatile action. In estuaries scoured by strong tides current action is also dominant, but they are in fact enlarged river channels alternately invaded by sea and river waters. In connection with irregularities in the coastline, waves also produce currents, as the result of concentrated undertow or obliqueness to the coastline. Such effects in seas and lakes are, however, local and exceptional as compared to the broad areas where wave action is dominant. The results of marine currents may be seen on the coast charts which show the entrances to Delaware and Chesapeake bays and also off Cape Hatteras. The conditions which give rise to wave-formed currents are connected especially with the inequalities of coastline resulting from a recent crustal movement and are rather closely restricted to shallow water and the vicinity of coasts. The waves and the currents which they generate are, however, in continual opposition, the one tending to fill up, the other to scour out. The leveling effects of strong wave action prevent in consequence such sharply defined and undercut channels as are developed by rivers. The slope of their sides probably does not average more than one in twenty-five, but the great volumes and consequent large

[26] Oral communication, Washington, D. C., December 29, 1911.

cross-sections of water carried by shore currents permit of local excavation to depths of several fathoms. Where progressive subsidence permits such features to become preserved, there may result lenses of marine sandstones some tens of feet in thickness and marked by cross-bedding. The slopes are not so steep, however, nor the cross-bedding on so large a scale nor so dominant as in either river or dune structures. The marine bars and channels are also relatively fixed and do not migrate over the surface so freely as do river channels and desert dunes.

In rivers where sands are being deposited the channel is subject to meandering. It cuts laterally into the banks and scours down into older floodplain deposits. The sands of the abandoned channels cut across the bedding of the floodplain deposits on the convex sides of the meanders and on the concave side are interlaminated with them. The river works across the floodplain and buries channel structures widely in the fluviatile deposits. The river bars work regularly downstream, being continually cut out above and deposited below. From these characteristics of river action it is seen that the resulting sandstone lenses tend to scour downward through the beds below and are marked by dominant cross-bedded and flow and plunge structures. Gravel tends to be especially concentrated along such channel bottoms. Lateral discontinuity of the sandstone lenses is also a feature, the ancient channel deposits forming a meshwork and giving sandstone courses rather than sandstone strata. Where the course of the river is relatively fixed during progressive subsidence, these channel sands and the sands of the natural levees may combine into a dominant sandstone facies, which may correspond in geological horizon to a shale formation at no great distance. Such local changes in facies mark the Siwalik formations and indicate the places of exit of the Tertiary streams from the Himalayas. Wave action, on the contrary, tends to spread out such a sand deposit over the zone where the bottom is sufficiently shallow.

River currents roll and jump material along the bottom in but one direction—a movement contrasted to the to and fro oscillating effects of waves. Typical ripple-mark is therefore exceptional, but in time of lessened velocity current-mark, an effect approaching it, is produced. The sand is caught between small back eddies on the bottom and the forward current, which is slightly higher. The result is the formation of crescents with gentle slopes facing upstream and steeper slopes facing downstream. The plan is more or less irregular and the individual ridges are limited in length. Current-mark is in fact analogous to dune structure, known as barchanes, rather than to the ripples made on the surface of

the dune or the ripple-mark made by the oscillations of waves. As waves and currents may operate together, there are, however, all gradations between ripple-mark and current-mark. In the papers which treat of the theory of ripple-mark no distinction has commonly been made between the effects of waves and currents, both producing back eddies along the bottom. It seems, however, to the writer from repeated observations that where made clearly by a single cause the two structures can be separated, waves producing a symmetrical system of ridges; currents, on the other hand, resulting in ridges which are unsymmetrical in both plan and section.

The cross-bedded structures of fluviatile sands are the result of the cutting out and filling in of channels and the downstream migration of bars; the slopes of the cross-bedding are commonly steep, from 15 to 30 degrees. Although showing considerable variation, they tend to slope in one direction. The character of the cross-bedded strata of alluvial fans has been described by Hobbs,[27] and several illustrations of cross-bedding ascribed to current action are given by A. Geikie.[28] Such cross-bedded strata are especially discontinuous and indicate broken currents and shifting channels. The effects are presumably much more striking than the cross-bedding produced where waves are a powerful factor. On the other hand, the thickness of a single cross-bedded stratum of fluviatile origin is normally limited to a few feet, and in that respect is distinct from the cross-bedding which results from the migration of dunes.

Contrasts of marine and fluviatile action.—The modes of action of seas and rivers on sand have been discussed at some length, as much to serve as a guide to further observation and to prevent premature generalization as to develop what is at present known. Under this heading will be drawn briefly a comparison between the two.

In marine deposits the coarser material is carried and deposited as the result of great storms; the finer interbedded material is the mark of lessened activity. In river action, on the contrary, the finer grained deposits of the floodplain are made as the result of the waters of great floods or the winds of dry seasons; the channel sands represent the silting up of diminished streams in the stages of lessened activity. The sands of the natural levees are spread out in sheets, however, at times of high water. The sea is dominated by wave action; the river and its sand-bearing floods are dominated by current action. The waves tend to spread sand in even sheets with evenly ripple-marked surfaces and a minute cross-

[27] Guadix formation of Granada, Spain. Bull. Geol. Soc. America, vol. 17, 1906, p. 291.

[28] Text-book of Geology, 1903, pp. 636-638.

bedded structure, giving flagstone bedding, but excessive wave action on a shallow bottom by developing waves of translation throws up bars and islands, beyond which the waves reform with lesser amplitude. In such cases beach action, shown by marked and irregular cross-bedding and even eolian effects, may be expected to become developed in places within the more regular formations of the flat bottom. The river currents, on the other hand, give an elongated structure to sandstone lenses, and tend to develop current-marked surfaces and more pronounced cross-bedded structures, instead of evenly bedded and ripple-marked sands, as the normal accompaniments of deposition. Waves tend to restrict the coarsest material to the zone of the shore, but finer gravel may be spread over the contiguous bottom in smooth even sheets. Rivers tend to concentrate such gravels into discontinuous courses.

Lenticular thickenings of marine sands should normally be convex upward and show flat cross-bedding. Channel sands, on the contrary, are more irregular, and although convex on the upper surface are more commonly convex at bottom, cutting through the underlying deposit and showing steep cross-bedding. These are the extremes of difference; but, on the other hand, evenly bedded almost structureless sands with minor cross-bedding may arise from the action of either sea or rivers. Although in extreme cases it is thought that sandstones of marine and fluviatile origin may be distinguished, it is clear that comparative studies of the two need to be carried out with a greater refinement than has heretofore been done, and that it is the character and dominance of a particular type of cross-bedding which is of significance rather than the mere presence of the structure.

Effects of sheet-flood deposition.—Many aggrading streams overloaded with sand exhibit at low stage shallow braided channels within the main channel. At higher water the main channels may likewise form a braided system, and at highest water the whole floodplain may be covered by a shallow moving water body, simulating on a larger scale the effects seen in the channels at low water. The effect is well illustrated in miniature by the waste banks from coal or ore washing plants. It seems to be emphasized over those piedmont slopes or deltas where aggradation is actively going forward and where the streams are always overloaded. In such cases the channel becomes an unimportant feature and sheet-flood effects arise.

It is such conditions which seem to be required to produce the great depths of regularly bedded and widely extended sandstones which mark certain continental deposits. The beds may vary from thin to thick. They succeed each other without interlamination of clays and commonly

show neither structure nor fossils. False bedding oblique to the even regular bedding is occasionally observed, but the homogeneous material conceals its frequent presence. Ripple and current marks, however, are rare or absent. Similar formations may possibly also be of marine origin, but it seems probable from the normal presence of wave action that ripple-marking should occur more commonly in the latter. It would seem unsafe, however, to assume in the present state of knowledge either a fluviatile or marine origin for a formation on the basis of such structures alone.

Effects of wind.—Cross-bedding and ripple-mark of most noteworthy development occur as the result of wind action on river or beach sands. In semi-arid or arid climates during the dry season the shrunken streams lay bare large areas of loose sands which are swept to leeward for indefinite distances. The delta of the Indus furnishes an example of such a fluviatile deposit greatly modified by wind action. The dunes of such regions advance by the deposition of successive layers of sand on the leeward face. With each change of wind some shifting of the dune takes place. The marching of the dune involves the continuous destruction and construction of the bedding, but in regions of aggradation the basal parts of the dunes remain and become permanently buried. Huntington has called attention to the fact that cross-bedding of eolian origin attains a much larger scale than cross-bedding by water currents. He shows also that eolian cross-bedding is furthermore deposited on curved surfaces which approach tangency to a horizontal plane at the bottom.[29] Aqueous cross-bedding, on the other hand, is commonly developed as plane slopes at a distinct angle to both the horizontal planes which limit the structure. These distinctions have been forcibly urged as evidence that the Triassic, and especially the white Jurassic sandstones of northwestern Arizona, are ancient desert sands.[30] If gravels occur in connection with such wind-blown sands certain of the pebbles may be expected to show the smoothed facets and sharp edges which are developed by wind action, giving rise where carried to perfection to the form of pebbles known as dreikanter. Ripple-mark on marine sands is best developed on nearly horizontal surfaces, since the action of the waves is closely limited by depth. Winds, however, are not so restricted in action and develop ripple-mark on the long sloping sides of dunes. Furthermore,

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[29] Some characteristics of the glacial period in non-glaciated regions. Bull. Geol. Soc. America, vol. 18, 1907, plates 36-38, pp. 351-388.

[30] Ellsworth Huntington and J. W. Goldthwait: The Hurricane fault in the Toquerville district, Utah. Bull. Mus. Comp. Zool., Harv. Col., vol. xlii, 1904, pp. 214-216.

Cornish states that in wind-made ripples the coarser grains rest at the crest of the ripples—in water they remain in the troughs. These distinctions should be of aid in separating eolian and therefore terrestrial from water-laid sands.

RELATIONS OF TEXTURE TO SEDIMENTATION

Degree of sorting a negative criterion.—On the whole, waves are more effective agents for sorting than river currents, but since rivers wear down gravel to sand in moving the bottom material downstream, all degrees of wear and sorting may be found in their deposits also, and distinctions founded alone on the degree of sorting are likely to lead to false conclusions. It is rather criteria drawn from the shape and association of the particles which must be invoked to separate fluviatile and marine material. But such distinctions if they are definite must await field study, and in this place the discussion may be restricted to the special case of the influence of wind in shaping material which enters finally into fluviatile and marine deposits.

Effects of wind in shaping sand.—This topic has recently received such full treatment by Sherzer,[31] who also gives abundant illustrations and references to the literature on the subject, that discussion may begin on the basis of his paper. Sand grains subjected to either wind, water, or glacial wear continued for a sufficient time come to consist almost wholly of quartz, and each type of abrasion gives characteristic forms. Wind wears fine sand much more rapidly than does water, moderate subjection to wind action giving a high degree of sphericity, which extends to grains which are less than a tenth of a millimeter in diameter, a size but little affected by water action. Subaerial exposure of loose sands is thus soon recorded in the form; but, as Sherzer notes, Sorby in 1880 called attention to the necessity of distinguishing between the age of the grains themselves and the age of the deposit in which they may be found.[32] The same caution regarding age applies to the mode of origin of the deposit as distinct from the mode of origin of the grains. The sands which enter into both river and marine deposits may at some time in their history have been subjected to the wind, and this may happen in rather close relationship to the final deposition. The relative opportunities for wind action in these two classes of deposits must therefore be discussed and the problem raised of separating true desert deposits

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[31] Criteria for the recognition of various types of sand grains. Bull. Geol. Soc. America, vol. 21, 1910, pp. 625-662.

[32] On the structure and origin of the non-calcareous stratified rocks. Proc. Quar. Jour. Geol. Soc. London, vol. xxxvi, 1880, p. 58.

which imply aridity from those other deposits where the wind has been merely a cooperating factor and has but minor climatic significance.

COMBINATIONS OF WIND AND WATER ACTION

Kinds of combined structures and textures.—The character and occurrence of such structures have been discussed elsewhere[33] and they need here be enumerated only. First, dune structures and dune textures prevail over the delta of the Indus, the material being derived from the river sands; second, facetted pebbles in sand deposits are common in the Great Basin of the United States from the fluviatile intermixture of sand and gravel, the latter being then subjected to wind scour by the sand; third, somewhat etched pebbles and millet-seed sand grains show a lesser degree of the same combined action in formations which are dominantly fluvial or pluvial; fourth, subangular pebbles, showing a dominance of disintegrating rather than decomposing activities in weathering, and exhibiting, furthermore, a lack of sorting in transportation characterize the local alluvium of semi-arid to arid climates, such as in the alluvial fans of the mountainous parts of Arizona and New Mexico; fifth, mud cracks made by the drying out of the floodplain clays may be filled by wind-blown sand and have been recorded as existing at the present time in both South Africa and South America.

Relative association of eolian action with fluviatile and marine deposits.—Dune structures bespeak a dominance of wind action, but in ancient formations appear to be relatively rare. Much more usual are the other marks of the wind which are subordinate to wave or river action. The more common of these are seen in the unsorted wash deposits, marking the local deposits of basins, in which wind may have played a very minor part; and the mud cracks filled by wind-blown sand extensively developed over semi-arid or arid floodplains. These structures in their modern examples are typically associations of river and wind action rather than shore and wind action, and are not by any means restricted to truly desert climates.

Those combined structures which are now found to an appreciable extent associated with the margin of the sea are the millet-seed texture and dune structures. The latter, however, are restricted to limited belts of what are chiefly submarine sands. Since the form of the sand grains persists after the dunes are destroyed, it is a much more pervasive phenomenon and is the feature which is more likely than the others to be developed in sands associated with the ancient epicontinental seas.

[33] Joseph Barrell: Relations between climate and terrestrial deposits. Journal of Geology, vol. xvi, 1908, pp. 279-284.

Modern examples outside of truly desert regions are found in the southwestern part of France, in the vicinity of the coasts, on the shores of Denmark and Prussia, and along certain stretches of the Atlantic coast of the United States. These are sands which have been thrown up by the waves or left by the retreat of the sea and show the widespread character of wind action under climates far from arid. Ancient examples of wind-worn sands which have received recent study are the Saint peter sandstone[34] and the Sylvania sandstone.[35] Of the origin of the Saint Peter sandstone Berkey says:

"The surface over which the Saint Peter sands were deposited was apparently very uniform. If it had departed far from a low-lying plain, we should doubtless have many marks of it in erosion forms characteristic of such elevation. On that plain, on its retreat, the sea spread great quantities of sand and left the marginal supply (Basal sandstone margin) exposed to all the transporting agencies. This the wind began to carry as dune sands along the shore. Into these sands the rivers sank as they coursed toward the retreating sea, accomplishing little in erosion. At the maximum retreat of the sea, it is the writer's belief that the Saint Peter sands presented the aspect of a shifting-sand plain, perhaps akin to a desert in this one feature at least, though not necessarily arid; so the sands were washed out by the retreat of the sea and thereby assorted, then worked many times over by the wind in the absence of the sea, and thereby still more perfectly assorted, and finally in the readvance of the sea much of it was again worked over a last time, thereby reaching its present remarkable condition of purity.

"That the Saint Peter sandstone was deposited in water and preserves chiefly such structures as are common to (water laid) sediments is certain; that its grains fall within the range of wind transportation and show characteristic wind-worn surfaces is equally clear; that the formation relationships argue an extensive retreat of the sea and an erosion interval is well supported—these factors alone are sufficient to account for all the peculiarities and remarkable characters of the Saint Peter, without any special agency." [36]

Concerning the Sylvania sandstone, Sherzer states that

"This sand in its purity, degree of rounding, and assortment has attained a degree of perfection that is being constantly approached, but never attained by any known modern example. It out-Saharas the Sahara! This perfected character of the Sylvania granules can be understood when the probable history is known, a lengthy and repeated buffeting with wind and wave, with no opportunity for the accession of new material and with a mineral substance inert to residual action." [37]

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[34] C. P. Berkey: Paleogeography of Saint Peter time. Bull. Geol. Soc. America, vol. 17, 1906, pp. 229-250.

[35] W. H. Sherzer: Op. cit.

[36] C. P. Berkey: Op. cit., pp. 246, 247.

[37] W. H. Sherzer: Op. cit., p. 651.

In the case of such formations, it is clear that other features than the wind-worn character of the sand must be relied on to determine the mode of origin of the final deposit, but on the basis of the structure Sherzer considers that much of the Sylvania is a truly eolian deposit.

Notwithstanding the examples just discussed, it is seen that under modern conditions eolian action modifies terrestrial and fluviatile deposits much more broadly than it does wave-worked sands. Rivers are efficient carriers of sand; thick deposits may be made over subsiding areas and much of each stratum is in turn broadly exposed to the air. Where the sedimentation is slow the wind is given fullest opportunity for work. On the other hand, sands which reach the sea are spread as widely as wave action is effective on the bottom, and it is only on the shore or on the upper portions of sands abandoned by a retreating strand that wind action can come into play. The associations of eolian action furnish, therefore, criteria of considerable value for separating formations chiefly marine from those chiefly fluviatile and should occur much more commonly in the latter.

CLIMATES IMPLIED BY EOLIAN ACTION

Desert climates and dominant dune structures.—There is necessarily no sharp distinction between the combined wind and water structures of arid climates and semi-arid climates, especially as surrounding uplands may possess a semi-arid climate and furnish water to the true desert below, or great rivers like the Nile may flow from well watered zones through regions of arid climate. The following general distinctions may, however, be drawn: In the true deserts wind is the dominating activity. It not only shapes the sand but is the agent which abrades the rocks and which sorts and transports both dust and sand. Where thick sandstone formations show dominant dune structure and wind-worn texture, as in the Jurassic white sandstones of Arizona, the inference is strong that ancient deserts probably prevailed.

Semi-arid climates and dominant combined structures.—It would appear that the degree to which wind action may modify the fluviatile or marine sands in semi-arid or even in humid climates has not been appreciated by some who have written of past conditions, nor that sufficient distinction has been drawn between semi-arid and arid climates, widely different in their terrestrial development and their relations to life. Red color, feldspathic sands, and the presence of some wind-worn material have been taken as evidence of desert conditions in the Torridonian pre-Cambrian and the Old Red Devonian sandstones of Scotland, although saline deposits are not present and the bulk of the material is such as

rivers and playa lakes could lay down. The writer has argued elsewhere that red as a color of consolidated formations may arise by dehydration of the iron during the diagenesis as well as during the deposition of the sediment and is liable to be produced in rocks as the result of any climate which permits occasional aeration of the alluvial soil.[38] Furthermore, the study of modern examples readily shows that fine-grained sandy alluvium may be modified by wind within the same broad climatic limits and does not necessarily imply desert climates. This is owing to the fact that a desert condition may be related to a barren sandy soil as well as to an excess of evaporation over precipitation. A sandy alluvium which permits the rain to run through it and which is too coarse to permit capillary retention of water may give rise to a local desert even with a high rainfall, and it is clearly erroneous to describe such conditions as implying a desert climate. For example, under the semi-arid climate of western Kansas and Nebraska the fine sands laid down by the Tertiary rivers are broadly reworked at present by wind and the surface of the land is ridged with dunes, yet the land supports great herds of cattle and was but recently the home of myriads of buffalo. In central Kansas sand is swept by wind from the bed of the Arkansas over the plains to the east to such an extent that the region is used as an illustration of dune topography by Chamberlin and Salisbury in their Geology.[39] This is in a region in which the mean annual rainfall is between 20 and 30 inches per year, with a maximum in early summer, but dry late summer. Still more significant are the sandy barrens of such regions as northern Prussia and Long Island and other areas of sand which were laid down as fluviatile outwash deposits from the Pleistocene glaciers.[40] The rainfall and temperature of these regions is such that if the loose sand can be protected from wind and sun action until a vegetable cover is established it will become reclaimed. Under the conditions of river building, connected with wandering channels and a continual supply of sand derived from them, the reclamation would apparently be more difficult. In earlier geologic ages the vegetation was presumably less specialized for such conditions and less effective in preventing wind action. Although its presence in moving and rounding the sand shows local desert conditions, it does not necessarily imply that such existed outside of the region of the deposit nor that there was a deficiency of rainfall.

Eolian action in arenaceous river deposits is thus seen to be peculiarly

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[38] Relations between climate and terrestrial deposits. Journal of Geology, vol. xvi, 1908, pp. 285-293.

[39] Vol. i, 1904, pl. II, fig. 2, p. 31.

[40] For an illustration from Connecticut see Bowman. Forest Physiography, 1911, p. 661. John Wiley & Sons.

favored by the nature of the material. It is especially characteristic of semi-arid climates, but extends beyond to a more limited degree into both arid and subhumid climates. It is commonly marked by such minor wind activities as the rippling of sandy surfaces and the filling of mud-cracked plains by sand. The latter is driven forward in a thin stratum without the development of dune structure unless the sand is very abundant and the winds are strong. The great quantity of animal life existing at present in the semi-arid districts of Africa and the great number and variety of footprints in the Triassic strata of Connecticut associated with these evidences of semi-aridity show how widely such climates differ in their life relations from true deserts, and a study of the rainfall maps of the world shows how characteristic are such climates of continental interiors and, in certain latitudes, even in the proximity of the ocean.

BREADTH OF EOLIAN ACTION AS A CRITERION OF FLUVIATILE DEPOSITS

The preceding sections have shown that river sands are much more broadly exposed to the air than sands of subaqueous origin; that sands where so exposed are subjected to wind action under climates which now widely prevail and support great quantities of life, and that certain combined structures of marked character not uncommonly arise. The conditions for the preservation of such evidences by burial are, furthermore, much more favorable in the case of aggrading rivers than for the deposits which fringe the shore. The arguments are therefore of cumulative force which show the value of partial wind action as a high but not absolute criterion of fluviatile origin and suggest the importance of careful search for such structures in ancient formations.

SIGNIFICANCE OF CONGLOMERATES

Gravels are transported by ice, by rivers, and by waves, giving rise to conglomerates of glacial, fluviatile, and marine origin. Glacial gravels may be eliminated from the discussion, leaving the distinctions between marine and terrestrial conglomerates to be considered.

W. D. Johnson pointed out that in the Tertiary deposits of the High Plains the gravel courses where exposed to observation are greatly elongated in the direction of the streams[41]—that is, in the direction leading away from the source of supply. Mansfield has noted that shore gravels, on the contrary, are extended in courses parallel to the margin of the deposit.[42] Ancient conglomerate formations, however, are commonly

[41] The high plains and their utilization. 21st Ann. Rept. U. S. Geol. Surv., part IV, 1901, p. 634.
[42] The characteristics of various types of conglomerates. Journal of Geology, vol. xv, 1907, p. 554.

folded or tilted, and it is seldom that a bed can be studied in two directions to a sufficient extent to determine the relations of the gravel strata to the direction of sedimentation.

Statements have been made regarding the characteristic shapes of river as contrasted to shore gravels. But these have been founded on few observations and without an analysis of the factors which determine the forms of the pebbles. Walther is certainly more safe in his conclusion that no distinction in form has been shown to exist between river and shore gravels.[43]

The subject of criteria between gravels of marine and terrestrial origin was considered by the present writer in a paper before the Geological Society of America in December, 1908. The pressure of other work and the extensive problem into which this subject developed have prevented thus far the final preparation of that manuscript for publication. As much of it, however, is nearly finished the subject will not be here rediscussed. In that paper "the problem was approached by studying the effects of shore, as compared with subaerial, activities on the production, transportation, and deposition of gravel. It was determined that the truly terrestrial forces produce vastly more gravel, spread it far more widely, and provide more opportunities for deposition than do the forces of the littoral zone. Conglomerate formations, therefore, should be dominantly of terrestrial origin. In order to determine, however, the mode of origin of particular examples, definite criteria must be drawn between the two classes. It was shown that the thickness was one of the most important of these, marine conglomerates, except under local and special circumstances, being limited to considerably less than 100 feet in thickness; terrestrial conglomerates, on the other hand, being frequently measured in hundreds and occasionally in thousands of feet.

"Attention was next turned to the significance of the intercalated nonconglomeratic beds and the relations to the under- and over-lying formations, with the conclusion that the characteristics of the associated strata are frequently of high supplemental value for determining the mode of origin." [44] Especially where the finer textured beds carry evidences of terrestrial origin the argument is strong that the associated coarser beds are also terrestrial. Where finer beds carry marine fossils the contiguous coarser beds are presumably in part if not wholly marine. Where, however, marine shales or sandstone are intercalated between conglomerate beds which are a hundred feet or more in thickness it is to be expected that at least the middle part of the conglomerates are terrestrial.

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[43] Einleitung in die Geologie, 1893, p. 757.

[44] Bull. Geol. Soc. America (abstract), vol. 20, p. 620.

Exceptional cases are known where these rules fail, chiefly on account of local accumulations of gravel through proximity to a bold shoreline, but it is thought that they have a high degree of generality. Thinner conglomerates may be either marine or terrestrial and their mode of origin must be determined on other grounds than that of thickness. The limit which has been rather arbitrarily drawn between sand and gravel by most writers is that of a diameter of two millimeters. For the application of these rules it should probably be raised to five millimeters.

Intraformational conglomerates made by wave action on shallow bottoms and not at the shore are readily discriminated, owing to the local origin and soft character of the pebbles and are not included in this discussion regarding the significance of thickness.

MUD CRACKS AND RAINPRINTS

In an earlier series of papers the writer has discussed[45] the relative proportions of continental, littoral, and marine sedimentation and reached the conclusion that deposits of the littoral zone, limiting that term to the land alternately flooded and laid bare at short intervals, are now and always have been small in area in comparison with the areas of marine and continental sedimentation. Furthermore, it was shown that littoral deposits were much more subject to destruction before being incorporated in the geological record. But mud cracks and rainprints are formed in any argillaceous or calcareous mud when dried either on river floodplains, over playa lake bottoms, and on the shores of either lakes or seas. Of these several situations the river plains, however, offer the most widespread and favorable surfaces for the development and preservation of mud cracks in argillaceous muds. Where the mud-cracked shales possess both a great horizontal and vertical range through formations the evidence is particularly strong for a fluviatile origin, as has been argued in the case of the Mauch Chunk shale of the anthracite coal basins.[46] The same argument applies to the Triassic formations of the eastern United States and certain pre-Cambrian formations. Under such conditions of characteristic occurrence through an argillaceous formation it is to be concluded, therefore, that mud cracks form one of the surest indications of continental origin. Several years of observations since these papers were written have served to strengthen the belief of the writer in this criterion. A few cases of mud cracks in shales, asso-

[45] Relative geological importance of continental, littoral, and marine sedimentation. Journal of Geology, vol. xiv, 1906, p. 550 et seq.

[46] Joseph Barrell: Origin and significance of the Mauch Chunk shale. Bull. Geol. Soc. America, vol. 18, 1907, pp. 449-476.

ciated with a marine or brackish water fauna, have been noted, but they are rare and limited in development.

In regard to mud-cracked limestones, however, the case is quite different. They are hardly to be explained by modern world conditions, and in 1906 they were purposely excluded by the writer from the discussion on mud cracks, as not sufficient data had then been accumulated to treat them. Since then numerous observations have shown the common occurrence of mud-cracked limestones in a number of Paleozoic formations, and leads to the conclusion that the seas of those particular epochs were essentially marine playas, extremely shallow pans of sea water. These were repeatedly emptied, not by the rapidly recurrent ebb and flow of tides, but possibly by monsoon winds or at longer intervals by extremely slight changes in the relative elevation of the playa bottom with respect to the sealevel. A related feature necessary to postulate in order to permit of such a condition was that the lands were so low or the rainfall so light that land waste and fresh water were not supplied in large quantities to these basins and the lime sediment was carried into them in solution by the sea. Land waters supplying almost wholly material in solution may also have contributed to certain formations. If waste had been supplied by the land in considerable quantities subaerial deltas would more or less completely have displaced the abnormally shallow sea and mud-cracked argillaceous deposits of continental origin would have been laid down.

TERRESTRIAL FOSSILS AS EVIDENCE OF TERRESTRIAL DEPOSITS

Free terrestrial fossils, plants, and animals.—Marine organisms are not washed inland by any usual process, but, on the contrary, rivers may carry river and land dwelling forms into lakes or seas. The problem is raised, therefore, To what extent are free terrestrial fossils safe criteria of terrestrial deposits? No discussion will be given here of what groups are to be safely regarded as terrestrial, but rather granting a terrestrial nature, To what extent may their remains become entombed in the deposits of permanent water bodies?

As to plants—trunks of trees and coarse vegetation are carried to sea in abundance by all large rivers whose channels are bordered by such plant life. Delicate parts, such as fronds of ferns and leaves, can not, however, be carried many miles without maceration, and their perfect preservation in abundance argues for the presence of swamps or small lakes.

In regard to the limitations in the occurrence of the bones of terrestrial animals, the most definite observations have been made by Hatcher. The

White River formations of Oligocene age which skirt the eastern base of the Rocky Mountains and extend outward for distances of from 200 to 300 miles are subdivided into, first, the Titanotherium sandstones and clays, overlaid by, second, the Oreodon clays, including the Metamynodon sandstones, and these in turn by, third, the Leptauchenia clays, including the Protoceras sandstones. Hatcher gives reasons on structural grounds and apart from the fossils for regarding the Oreodon and Leptauchenia clays as of floodplain origin. The clays hold, furthermore, thin layers of limestone which mark the former presence of small ponds and lakes. The included Metamynodon and Protoceras sandstones are the deposits of the river channels. Each of these subdivisions holds a distinct fauna and flora. The clays contain numerous remains of giant land tortoises and the scattered and fragmental skeletons of such great mammals as the Titanotheres. The limestone lenses within the clays are rich in the remains of fresh-water plants and mollusca, whose habitats are swamps and ponds. The sandstones are more sparingly fossiliferous, but contain the remains of aquatic turtles, fishes, and crocodiles, and in one locality the casts of unios were observed in great numbers. Hatcher comments, further, that the bodies of animals will only be swept into lakes or the sea while they are intact and distended by gases and will ordinarily become buried as complete skeletons.[47] It would seem possible, however, that even large terrestrial animals might be preserved intact within the zone of terrestrial deposition, seeking shelter in groups in the lee of cliffs, or dunes, or mired in water holes. *A priori* it might be expected that but little significance could be attached to the place of burial of a large mammal; but, considering the truly terrestrial fauna, the observations of Hatcher and general geological experience point to the conclusion that their fossils are but rarely found entombed in ancient lake or sea bottoms.

Fixed terrestrial fossils, plants and animals.—These are evidences of the highest value as to terrestrial conditions of origin. Progress in paleobotanical studies has shown that the great majority of coal seams consist of the debris of fresh-water swamps in place, though in the case of bogheads and cannels the seam represents metamorphosed sapropelic deposits of lacustrine origin, and some deposits of coal may be due to material drifted into large lake basins by river agency.[48] No salt-water adaptations of coal plants have been demonstrated, so that these as well

[47] Origin of the Oligocene and Miocene deposits of the Great Plains. American Phil. Soc. Proc., vol. xli, 1902, pp. 113-131.

[48] F. E. Weiss: Address to the Botanical Section, Brit. Assoc. Adv. Sci. Science, n. s., vol. xxxiv, 1911, p. 475.

as stumps and roots in place show the fresh-water and continental origin of the beds. As the swamps are in large part, however, on the seaward portion of the subaerial delta beds, a large part of the associated strata is normally marine. This is true, however, of the outer parts of the coal measures only, and on the landward side the whole series may be of terrestrial origin.

In most of the red bed formations oxidation has destroyed all plant tissues, but in the Catskill of the Upper Devonian and the Mauch Chunk of the Mississippian the writer has found the casts of deep-seated branching rootlets *in situ*,[49] evidence of terrestrial origin of a positive nature, and especially valuable in such formations on account of the usual paucity of evidence.

The footprints of land animals, and especially herbivorous land animals, are most commonly made on the margins of fresh water. Amphibians at the present time avoid salt water as a fatal environment, and a similar antipathy has doubtless existed in the past. Footprints are, therefore, evidence of terrestrial origin and fluviatile deposition of the same degree of probability as that furnished by plants. As exceptions to this rule it should, however, be noted that a marine mollusk (Nuculana) is preserved on the same slab with the oldest known footprint,[50] and footprints of vertebrates in the coal measures of Kansas are preserved in shales which hold a few marine shells.[51]

General Conclusion on Criteria for Delta Deposits

From this review of the criteria which serve to separate the terrestrial portion of delta deposits from those of subaqueous origin several conclusions may be drawn. First, it is seen that it is more commonly the particular form of a feature, such as cross-bedding or the thickness of conglomerates or the mode of preservation of bones, which is of distinctive value, rather than the mere presence of cross-bedding or conglomerates or fossils; second, a single criterion is in many cases not absolutely decisive, and it is the convergence of evidence which makes strong the conclusion in regard to the origin of strata of a particular horizon; third, it is unsafe to extend the conclusion beyond the limits of the evidence to other portions of the same formation. Notwithstand-

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[49] Origin and significance of the Mauch Chunk shale. Bull. Geol. Soc. America, vol. 18, 1907, pp. 460-462.

[50] O. C. Marsh: Amphibian footprints from the Devonian. American Journal of Science, vol. ii, 1896, p. 375.

[51] O. C. Marsh: Footprints of vertebrates in the coal measures of Kansas. American Journal of Science, vol. xlviii, 1894, p. 81.

ing these limitations, it is thought that the criteria are sufficiently varied and numerous to determine the conditions of origin of the great majority of delta deposits. Finally, there should be emphasized the need of much broad study of a quantitative nature regarding modern conditions of sedimentation to determine minutely the characteristics which become a recognizable part of the buried formation as distinct from the passing surface features. The development of distinctive criteria must be studied, furthermore, in relation to the physiographic and climatic conditions of origin. This is a line of progress begun in the early days of geology, but then essentially of a qualitative nature, and by Lyell made the basis of the interpretation of earth history. Having grasped this idea the centers of scientific interest were transferred to the geologic record, and the interpretations made by the generation of Lyell were carried forward without material improvement till near the close of the nineteenth century. It is clear, however, that a more accurate and quantitative knowledge of that earth history which is now being recorded is needed in order to obtain in turn a more accurate knowledge of the past. Many of the criteria which in this paper are considered somewhat indefinite may become definite through a wide and more discriminative study of the sedimentation now in progress.

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A MISSISSIPPIAN DELTA[1]

BY E. B. BRANSON

(*Read before the Society December 29, 1911*)

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INTRODUCTORY

During the summers of 1907, 1908, and 1909 the writer investigated the geology of parts of Bland, Giles, Pulaski, and Montgomery counties of northern Virginia. Four weeks of 1908 were spent north of Narrows, on New River, and two weeks 12 miles south of Narrows, where the Dublin-Pearisburg road crosses Cloyds Mountain. In the former region most of the Mississippian formations can be studied and in the latter a fine section is exposed. The sections are so strikingly unlike that some time was spent in attempting to account for the differences. The outcrops occur in parallel belts striking northeast-southwest. The dip is generally above 45 degrees, and between the two lines of outcrop all rocks younger than the Devonian have been removed by erosion. As near as can be determined from available data, the regions were about 36

[1] Manuscript received by the Secretary of the Society February 26, 1912.

miles apart before folding and faulting took place, and the drawing that accompanies this paper is an attempt to represent the original structure and relations of the formations.

Comparison of Mississippian in Cloyds Mountain and north of Narrows

The formations in Cloyds Mountain consist of 757 feet of Price[2] sandstone overlain by 2,578 feet of Pulaski shale, but the total thickness is undetermined, as the top of the Pulaski is faulted out. The Narrows section shows 200 to 300 feet of Price sandstone, 20 to 30 feet of Pulaski

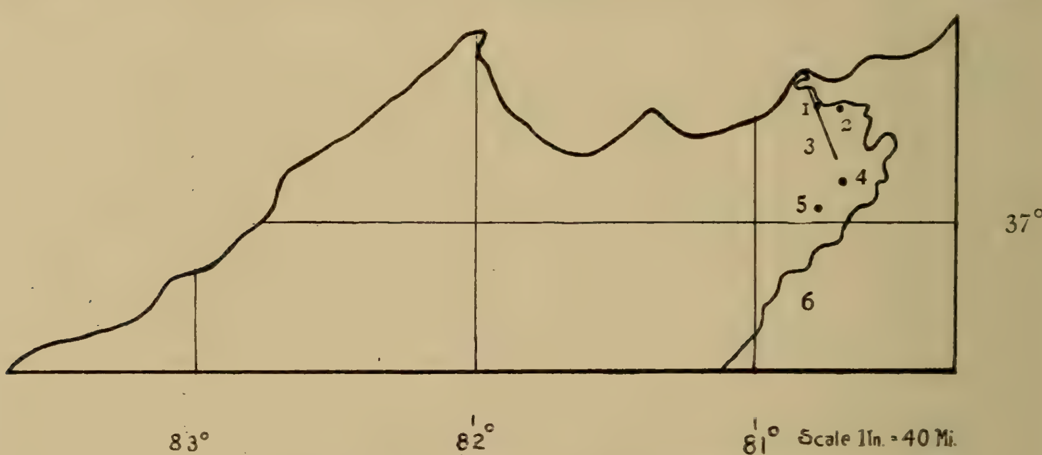

FIGURE 1.—*Virginia West of Roanoke*

1. Narrows
2. Pearisburg
3. Section line
4. Dublin
5. Pulaski
6. New River

shale, 1,180 feet of Greenbrier limestone, 1,350 feet of Bluefield limestone, sandstone, and shale, and 1,200 to 1,300 feet of Hinton sandstone and shale. The measured thickness at Narrows is about 4,000 feet and in Cloyds Mountain 3,338 feet, but as the top is missing in the latter the total thickness may be as great or greater than at Narrows.

Section of the Mississippian in Cloyds Mountain

PULASKI SHALE

The Pulaski is a variegated shale ranging in color through various shades of pink, yellow, green, blue, and purple. The colors change fre-

[2] These formation names are used by M. R. Campbell, in folio 26 of the U. S. Geological Survey, for the Pocahontas area, which lies 10 to 15 miles west of the area under discussion.

In his map of the Cloyds Mountain area M. R. Campbell shows no Pulaski along the Dublin-Pearisburg road, but its outcrops are excellent for nearly a mile across the strike. The road crosses the mountain about half way between the western end of the Pulaski outcrop and "Cpr," at the northern edge of Campbell's map.—Bull. Geol. Soc. America, vol. 5, pl. 4.

quently along the strike of the same beds. Four or five beds of sandstone, 2 to 15 feet thick, occur with the shales. No fossils were found in the formation, though careful search was made for them. The measured thickness along the Dublin-Pearisburg road is 2,578 feet, but, as explained above, this is not the total thickness. The top of the Pulaski of the southern line of outcrop, which occurs typically in Little Walker and Cloyds Mountains, is faulted out wherever the writer has examined it, and this seems to have been the case wherever measurements were made by Campbell, Stevenson, and Fontaine. Occasional presence of mud cracks, absence of fossils, and variability of sediments in character and color indicate subaerial origin.

		Feet	In.	Feet
	Fault with Shenandoah limestone against Pulaski shale.			
12.	Variegated shale, with many shades of red, pink, yellow, blue, and purple. Much like number 4......			963
11.	Greenish yellow sandstone, weathering red...........................			4
10.	Like number 4......................			92
9.	Purplish red, sandy shale...........			282
8.	Like number 4.......................			532
7.	Fine-grained, friable, brick-red sandstone...........................			30
	Pink shale.................	7	..	
	Yellow to pink shale........	14	..	
6.	Pink to yellow shale........	10	..	
	Purple shale................	2	..	
	Greenish yellow shale.......	3	..	
				36
5.	Greenish yellow, hard, sandy shale............................			40
	Purple shale................	2	6	
	Greenish yellow shale......	5	..	
	Purple to pink shale........	5	..	
	Yellow shale................	7	..	
	Purple shale................	3	..	
	Pink to yellow shale........	12	..	
	Purple shale................	2	6	

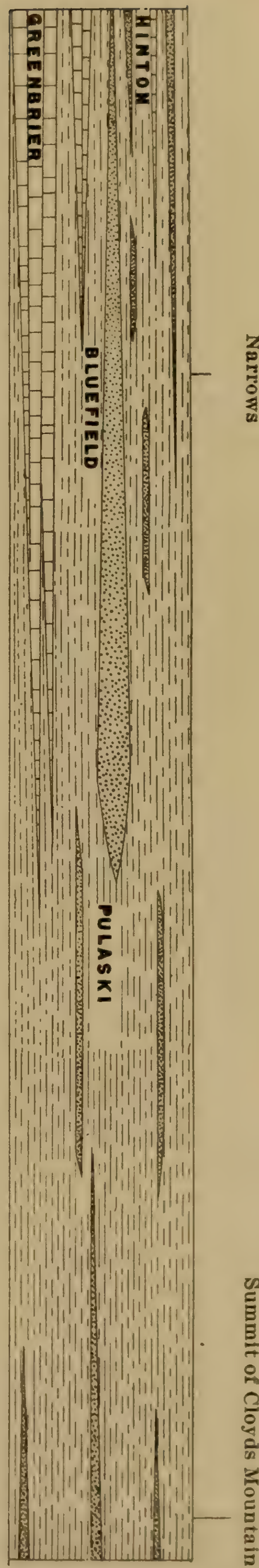

FIGURE 2.—*Hypothetical Condition of Strata before Folding*

Along a line from 4 miles north of Narrows, Virginia, to the summit of Cloyds Mountain on the Dublin-Pearisburg road

Horizontal scale: one-half inch equals one mile Vertical scale: one inch equals 5,000 feet

	Feet	In.	
Red and yellow shale (partly covered)	85	..	
Pink shale	5	..	
Red and yellow sandstone	10	..	
Yellow to pink shale	29	..	
Yellow to green shale	10	..	
Pink shale	15	..	
4. Green shale	2	6	
Yellow shale	20	..	
Pink to yellow shale	18	..	
Greenish yellow shale	5	..	
Red shale	9	..	
Yellowish green shale	7	..	
Red shale	2	6	
Yellow shale	2	6	
Pink to green shale	7	6	
Red shale	2	6	
Pink shale	8	..	
Green shale	2	6	
Brick-red sandstone	18	..	
Pale green to pink shale	2	6	
Green shale	2	6	
Red sandstone	5	..	
Purple and green shale	2	6	
Pink shale	8	..	
Greenish shale	2	6	
			322
3. Red to yellow sandstone, friable			12
2. Like number 4			224
1. Hard, greenish yellow, sandy shale			40
Total thickness of Pulaski from the bottom to the level, where it is truncated by a fault			2,578

PRICE SANDSTONE

The Price consists mainly of cross-bedded coarse sandstone, with several thin beds of conglomerate near the bottom and shales alternating with the sandstone near the top. The measured thickness is 757 feet. Three beds of coal, with a total thickness of about 7 feet, occur near the middle of the formation. No marine fossils were found excepting in the lowest beds, but plant remains are abundant in connection with the coal. *Lepidodendron scobiniforme* Meek,[4] a characteristic Pocono plant, is the most common form. The presence of coal, the absence of marine fossils, and the character of the sediments indicate subaerial and freshwater origin. The Price grades into the Pulaski above and Kimberling below without distinct planes of demarkation.

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[4] Identification by David White.

	Feet
29. Yellow to reddish, in places brick-red, friable sandstone	53
28. Purple to black shale	5
27. Yellowish sandy shale	8
26. Black to purple shale	6
25. Fine-grained, friable, yellow sandstone	15
24. Light yellow shale	12
23. Pink to dark yellow shale	16
22. Light yellow shale	12
21. Bituminous shale, with thin bed of coal. Plant remains abundant	10
20. Yellow to brick-red sandstone	100
19. Bituminous shale, with about 3 feet of coal. Plant remains abundant	10
18. Yellow shaly sandstone	6
17. Red sandstone	1
16. Yellow, finely laminated shale	24
15. Bituminous shale. Plant remains at bottom	12
14. Coal	4
13. Coarse-grained, gray to yellow sandstone, very firm	19
12. Coarse-grained, friable, yellow to pink sandstone	23
11. Gray, thick-bedded, concretionary sandstone. Concretions up to 5 feet in diameter	17
10. Thick to thin bedded, friable sandstone, some almost shaly; gray, pink, red	195
9. Coarse-grained sandstone, thick-bedded, firm, yellowish gray	10
8. Yellow to pink sandstone, very friable, with a few thin beds of firm sandstone	53
7. Sandstone made up largely of concretions	3
6. Shaly sandstone, yellow, gray, pink, red	88
5. Gray, thick-bedded, conglomeratic sandstone	11
4. Yellow to pink sandy shale	17
3. Conglomerate	4
2. Yellow to pink sandy shale	15
1. Gray conglomerate, pebbles up to more than an inch in diameter	6
Total thickness of Price	757

Section of the Mississippian in the Narrows region

Area of observation

Most of the observations on this section were made about 4 miles north of Narrows along New River, and wherever the Narrows area or section is mentioned reference is to this place.

Hinton formation

This formation was not measured or described in detail by the writer. In the Pocahontas region west of Narrows, M. R. Campbell describes it as consisting of a "variety of beds of calcareous shale, impure limestone, red argillaceous shale, sandy shale, and sandstone" 1,250 to 1,350 feet in

thickness. The variegated shales would be emphasized to a much larger extent in describing the formation in the Narrows area. During the early part of the work in this region the writer believed that these were the Pulaski shales, basing his belief on the published descriptions, together with the rather deceptive fact that some of the Mississippian strata are reversed, owing to an overturned fold. Marine conditions seem to have given place to nonmarine at the opening of Hinton time, but recurred for short periods several times before the close of the age. Evidences of subaerial origin are amphibian footprints preserved in the lower part, variegated colors of the sediments, presence of partly decayed tree trunks, and absence of marine fossils excepting at a few horizons.

BLUEFIELD FORMATION

It was found impossible to obtain a complete description of the Bluefield in the Narrows region, but at Peterstown, 2 miles to the east, the entire section is present. The Bluefield grades gradually into the Hinton.

	Feet
15. Dark bituminous shales, with occasional 1 to 2 inch beds of very fossiliferous limestone	170
14. Dark limestone and shale alternating. Limestone beds thin above and thick below	235
13. Dark shaly limestone appearing to be in thick beds	148
12. Light-green shale	11
11. Bluish to greenish shaly limestone and sandy shale	7
10. Reddish to purple sandy shale grading to light green above	11
9. Greenish to brownish compact thin-bedded sandstone	91
8. Blue limestone	15
7. Shaly limestone, blue to yellow	115
6. Light-blue shaly limestone	51
5. Thick-bedded coarse blue limestone	37
4. Green calcareous shale to shaly limestone	100
3. Green thin-bedded shale	192
2. Alternating black and yellow shale	15
1. Soft yellow shale	15
Total thickness of Bluefield formation	1,213

GREENBRIER LIMESTONE

The Greenbrier consists of limestone with more or less chert below and alternating limestones and shaly limestones above. It is not sharply differentiated from the Bluefield above.

	Feet
41. Alternating greenish gray to blue limestones and calcareous shales	24
40. Blue limestone	160
39. Thick-bedded gray limestone	9

	Feet
38. Green shaly limestone	7
37. Blue limestone	16
36. Greenish shaly limestone	24
35. Gray calcareous shale to shaly limestone	9
34. Greenish gray shaly limestone	28
33. Like number 35	9
32. Greenish gray shaly limestone (partially covered)	172
31. Covered, but grading into thick-bedded green limestone at top	28
30. Probably like 7, but partially covered	80
29. Like 35	40
28. Light-blue shaly limestone	6
27. Like 35	21
26. Like 34	12
25. Like 35	3
24. Like 34	2
23. Like 35	4
22. Like 34	9
21. Like 35	9
20. Like 34	12
19. Like 35	12
18. Like 34	1
17. Coarse-grained blue limestone, crinoidal, cherty near the top	72
16. Like 35	28
15. Blue limestone	2
14. Like 35	30
13. Bluish gray medium-grained limestone	14
12. Light gray to yellow shaly to thick-bedded limestone	7
11. Thick-bedded blue limestone	45
10. Like 12	19
9. Grayish blue coarse-grained limestone	19
8. Like 12	48
7. Like 9	9
6. Greenish gray shaly limestone	14
5. Blue limestone	2
4. Like 6	36
3. Blue limestone containing some chert	112
2. Cherty blue limestone, chert black	32
1. Very dark blue thin-bedded limestone	54
Total thickness of Greenbrier	1,240

PULASKI SHALE[5]

The Pulaski is 22 feet thick here compared to nearly 3,000 in the Cloyds Mountain section. It consists of the same kinds of shale as in

[5] This section was measured by Mr. H. E. Wilson 3 miles west of the Narrows area, along the Norfolk and Western Railway. The writer examined the section after Mr. Wilson had described it.

the southern area, but bears some coal. The change from the Pulaski to the Greenbrier is abrupt.

	Feet	In.
9. Light gray to blue gray, thin to thick bedded, calcareous shale....	11	..
8. Greenish gray shale..	..	4
7. Compact, red shale...	3	4
6. Greenish gray shale, slightly micaceous, streaked with carbonaceous material and limonite. A few inches to.....................	..	1
5. Like 7	2	..
4. Like 6	1	6
3. Like 7	2	..
2. Like 6	1	5
1. Carbonaceous shale to coal..................................	..	4
Contact with the Price sandstone.	22	..

PRICE SANDSTONE (POCONO)

In the Narrows section the Kimberling shale is faulted up against the Greenbrier limestone and no Price outcrops. Three miles to the west along the Norfolk and Western Railway an outcrop occurs, but part of the formation is faulted out. The thickness is estimated at 200 to 300 feet, but the estimate is not based on sufficient data. Well data to the north give no aid, as it is impossible to determine the bottom of the formation from such data.

The thinning of the Mississippian away from the Cloyds Mountain Area

The Pulaski thins to the northeast, north, northwest, and southwest from the Cloyds Mountain region and is absent east and southeast. In the Max Meadows region, 30 miles southwest, the Greenbrier rests on the Price and the Pulaski is absent. In the area described in the Pocohontas folio, which begins about 15 miles west of the Cloyds Mountain section, the Pulaski is 30 to 300 feet thick, apparently being thickest nearest the Cloyds Mountain area and thinning away from it. Fifty miles northeast it is 200 to 300 feet thick, but the top may be absent. The Price sandstone thins in the same directions as the Pulaski, generally falling from 757 feet to 200 or 300 feet within a few miles.

Interpretation of the Conditions

The following is presented as an interpretation of the history of these regions in Mississippian time. With the close of the Devonian or early in the Mississippian the sea basin from north of Narrows to south of Cloyds Mountain was filled above sealevel and coastal swamps in which

abundant vegetation grew prevailed. Sinking incident to the consolidation of the underlying 5,000 feet of Devonian sediments and to crustal warping kept the land near sealevel while the Price was being deposited. During Pulaski time subaerial sedimentation continued in the southern area and the southern shoreline of the Appalachian Sea lay north of Cloyds Mountain.

In the Narrows area, originally 30 miles to the north, subaerial conditions of sedimentation ceased after 300 feet of sandstone, shale, and coal had been formed. The sea then advanced from the north and limestone-forming conditions began. During the deposition of 1,200 feet of limestone of the Greenbrier sedimentation was nearly uniform, but following this the shoreline again retreated from the south, the water became turbid at intervals, and alternating sands, muds, and calcareous deposits about 1,300 feet thick were deposited. With the beginning of Hinton time the shoreline retreated to north of Narrows and subaerial sedimentation began. Most of the 1,200 feet of sandstones and shales of the Hinton in the Narrows region were deposited landward from the sea margin, but the sea advanced to the southward and again retreated several times during the age and thin layers of marine strata interwedge with thick beds of continental.

The Price and Pulaski of the Cloyds Mountain region are assumed to be part of a great delta because:

1. They reach their maximum thickness here and thin rapidly north, east, and west.

2. For the most part they are clearly subaerial deposits.

3. The margin of the sea was only a few miles to the north during most of Pulaski time, and conditions here must have been similar to those of the present Mississippi delta near the sea margin.

According to this hypothesis the Pulaski, Bluefield, Greenbrier, and Hinton of the northern area are to be correlated with the Pulaski of the southern. Stevenson believed this to be true, but M. R. Campbell[6] thinks that conditions in the Cove region in Wythe County entirely disprove such a correlation. In this region the Greenbrier rests directly on the Pulaski, but the evidence is entirely negative as to whether any of the Greenbrier is of the same age or younger than the Pulaski.

Conclusions

1. During Mississippian time the region of Cloyds Mountain, Virginia, was part of a great delta and was generally the site of subaerial deposition.

[6] Bull. Geol. Soc. America, vol. 5, p. 178.

2. Thirty miles north of the Cloyds Mountain region the Mississippian began with the land emerged, but the sea soon advanced from the north and initiated limestone-forming conditions, which were succeeded by marine sandstone and shale forming conditions, which were followed by subaerial conditions.

3. The Pulaski shale, Greenbrier limestone, Bluefield formation, and Hinton formation of the northern region are equivalent to the Pulaski of the southern.

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BOULDER BEDS OF THE CANEY SHALES AT TALIHINA, OKLAHOMA[1]

BY J. B. WOODWORTH

(*Presented before the Society December 30, 1911*)

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INTRODUCTION

The Caney shales, described by Taff[2] in 1904, were later characterized as a formation by Girty[3] in the following terms:

"The Caney shale occurs in numerous exposures through the Arbuckle and Ouachita Mountains, in the central parts of the Choctaw and Chickasaw nations, respectively. It consists of black and blue argillites, with local sandy strata in the upper part, and has a maximum thickness of more than 1,000 feet. While most of the Caney is a black shale, the upper portion comprises beds of a lighter color which may have a different fauna."

The fauna of the Caney shale is marine. Girty very guardedly referred the beds to the Pottsville, which reference Ulrich[4] later proved to be correct on stratigraphic and faunal evidence.

In 1909 Mr. Taff, in a paper read before this Society,[5] called attention to a remarkable boulder bed occurring in the lower part of the Caney shale. In three localities in the Ouachita Mountains, limestone and flint boulders were described as bearing grooves and striæ, the origin of which

[1] Manuscript received by the Secretary of the Society January 4, 1912.

[2] Joseph A. Taff: Preliminary report on the geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma. Professional Paper No. 31, U. S. Geol. Survey, 1904, pp. 33-34.

[3] George H. Girty: The fauna of the Caney shale of Oklahoma. Bull. No. 377, U. S. Geol. Survey, 1909, p. 5.

[4] In a note to the author commenting on the paper read before the Society.

[5] Joseph A. Taff: Ice-borne boulder deposits in mid-Carboniferous marine shales. Bull. Geol. Soc. America, vol. 20, 1909, pp. 701-702.

was discussed and the inference drawn that the boulders were transported by floating ice.

Ulrich,[6] who shared the investigation of these erratics with Taff, stated his conclusion regarding the transportation of the boulders in a brief footnote in 1911 as follows:

"The assumption of locally frigid conditions in the early Pennsylvanian is based primarily on the fact that erratics of all sizes, some as much as 20 feet across and 5 or 6 feet thick, occur in the Caney shale of eastern Oklahoma. These were transported not less than 50 miles, and many probably were carried much farther. No other competent means of their transportation than ice—presumably heavy shore ice—has been suggested."

The doubt expressed by Mr. Taff concerning certain of the striæ and a desire to compare the striated rocks with known examples of Paleozoic glaciated stones led the writer, in August, 1911, to visit the most promising locality for striated boulders in the railroad cut northeast of the hamlet of Talihina.[7]

Criteria of glaciated Stones

As the question at issue is the nature of the striæ in certain of the stones, the criteria of certain groups of striæ may first be set forth. Glacial striæ on rock fragments held between the bottom of a glacier and the rock-floor or between that floor and a boulder through which the weight of the moving ice is transmitted are typically scratched, however deep, by a process in which the material of the striated stone is crushed under pressure and removed as powdered rock or fine particles. In the case of consolidated rocks undergoing glacial striation the resultant striæ show no trace of flowage of the rock in the process. This is for the reason that, however great the weight of the overlying ice, the crushing strength of ice is less than that of the weaker consolidated rocks, and the ice will yield before the pressure in the zone of striation of rock fragments reaches the pressure at which the shearing and reconsolidation of crushed rock particles takes place. Moreover, the ice, owing to its property of flowage under pressure, readily permits the crowding of the stones and boulders used as striating tools into new positions. In the case of very great pressure it is held by some physicists that pressure-melting of the bottom ice takes place, and consequently striation at this point would cease because of the deposition of the rock-matter in the subglacial zone of pressure-molten water. For these rea-

[6] E. O. Ulrich: Revision of the Paleozoic systems. Bull. Geol. Soc. America, vol. 22, 1911, p. 352, footnote.

[7] I am indebted to Mr. Robert W. Sayles, curator of the Geological Section of the University Museum of Harvard University, for personally defraying the field expenses incurred in visiting Oklahoma.

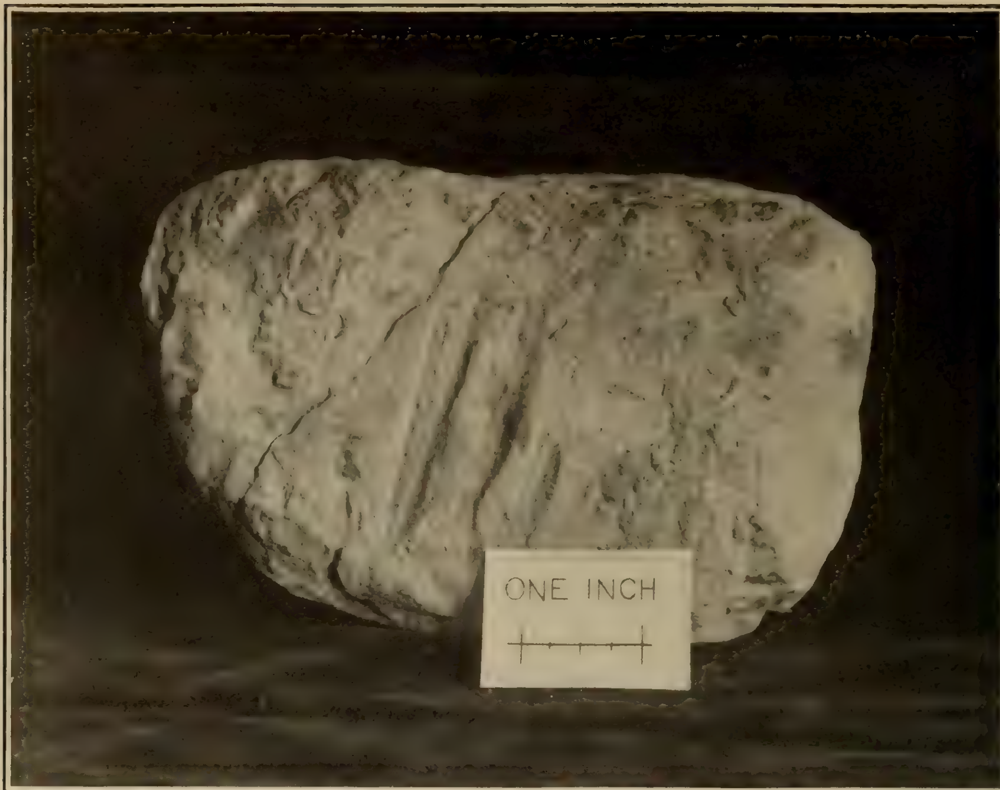

FIGURE 1.—BOULDERET, SHOWING SLICKENSIDED SURFACE AND PRESSURE CRACK
Ordovician limestone in Caney shale: Talihina, Oklahoma. Photo by Turpin

FIGURE 2.—CHEMICALLY PITTED PEBBLE OF ORDOVICIAN (FOSSILIFEROUS) LIMESTONE
Showing slickensides on protuberance (above "Inch" on scale) where intersected by plane of gliding in the Caney shales: Talihina, Oklahoma. Photo by Turpin

SLICKENSIDED PEBBLE AND BOULDERET FROM CANEY SHALES AT TALAHINA, OKLAHOMA

sons glacial striation never partakes of the schistose structure subparallel to faulted surfaces whose motion has taken place under earth pressures.

In the case of glacial striation the striæ are normally single and those on the movable rock fragment take diverse directions owing to the frequently changed attitude of the fragment. Only in the case of the rock-floor or of large blocks lying at the side of the glacier do striæ normally develop in parallel groups, and in these instances the striæ retain the character of single successive scratches made by passing rock particles held in the moving ice.

Striæ of the Caney Shale Pebbles

The striæ and scratches on the boulders and pebbles in the Caney shales are characteristically in groups of parallel striated grooves, in which the intervening ridges are ribs the counterpart of the grooves in appearance. A sort of flowage structure or cleavage pervades the structure of the rock for a slight depth, showing that the striation took place under conditions of great pressure, as in deep faulting with slickensides.

In the case of some striated pebbles fragments of a different rock remain in contact with the pebbles at the end of a surface of gliding and striation, showing that the striation has been accomplished by rocks in motion within the shale body.

The surface of some of the limestone blocks displays a flowage contour like that of clay under pressure. All the phenomena of striation and flowage of the rock fragments in the Talihina cut coincide with the contortion and slickensiding of the Caney shales at this locality in suggesting the conclusion that the striæ on the pebbles and boulders are an effect of interstitial motion and displacement subsequent to the deposition of the Caney shale. An ironstone concretion formed in the contorted shales displayed the broad striated grooves such as are displayed on the limestone boulders and pebbles (see figure 1, plate 23).

Comments of Ulrich

In commenting on my verbal communication before the Society, Doctor Ulrich made the following pertinent statement concerning the occurrence of striated pebbles in the Caney shales far south of the crushed beds near the Choctaw fault:

"The best of the many striated boulders found by Taff and myself was found in the middle portion of a gently folded structural canoe far to the south of the Choctaw fault. The boulder is of flinty chert, its outer surface rather soft and partially decayed to a depth of one-fourth inch or so. The striæ are deep, though confined to the relatively soft outer shell, and the edges of the grooves raised as though plowed in a plastice mass; and yet the inclosing shale is

here nearly horizontal and most certainly not contorted as it is in the Talihina cut. Your criteria, therefore, do not account for this example. The raised edges bordering some of the grooves in this specimen are hard to explain. The only explanation that has suggested itself as possibly competent is that the surficially decomposed boulder was covered by soft mud when some heavy mass of shore-ice, studded beneath with fresher chert pebbles, plowed through the cover of mud and into the soft surface of the boulder. The material thus gouged out of the boulder might, under the circumstances mentioned, be pushed aside under the cover of mud and be preserved in this position when the mud again settled into the plowed furrow.

"Regarding the great majority of the striated boulders seen by me in and in the vicinity of the Talihina cut, I agree thoroughly with you in ascribing their furrows to scratching by associated pebbles during the course of movements within the contorted shale itself. The evidence favoring this conclusion, as agreed on the ground by Hayes, Taff, and myself, was in several cases conclusive. But even here occasional boulders bore striæ that could not be satisfactorily explained in this manner. Your figures 1 and 4 suggest examples of the latter class. At any rate your interpretation of these instances does not seem to me altogether satisfactory. Essentially the same kind of grooving would have resulted if the pebbles had been embedded in the bottom of floating ice and dragged over the rough silica-studded surface of previously dropped boulders. I have frequently observed boulders in the Caney, some of them 6 to 10 feet across, whose surface was studded with small projecting silicified fossils that must have scratched any relatively soft limestone that may have been dragged over them under the weight of a floating mass of ice. They would have plowed furrows into the prominent parts of faces of the moving pebble just as an iron planer cuts the projections off the mass of evenly moving steel as they come into contact with the stationary cutting tool."

Remarks on Ulrich's Comments

As to the striated grooves in figures 1 and 4, which appear from their photographs to Doctor Ulrich not to be of the nature of slickensided stones, it should be stated that in both cases the markings differ from glacial striæ in that from point to point the striated surfaces display the same striation pervading for a slight depth the structure of the rock, as is the case with the incipient cleavage accompanying slickensides. This seems not to me to be a characteristic of the ice striation of hard rocks, such as these Ordovician limestones must have been when transported. I do not see how these limestone boulders could have been softened by decomposition without being dissolved. As for the striations on boulders at other localities in Oklahoma, I have not seen the localities nor the materials, and can only suppose as does Doctor Ulrich that where grooved and striated stones occur in undisturbed horizontal beds that the striation was accomplished by some form of ice action prior to the final deposition of the erratics. I saw no stones in the Talihina cut which at the time of my visit struck me as scratched by ice action.

FIGURE 1.—SLICKENSIDED FRAGMENT OF ORDOVICIAN LIMESTONE, WITH INDENTED PEBBLE

From Caney shales: Talihina, Oklahoma. Photo by Turpin

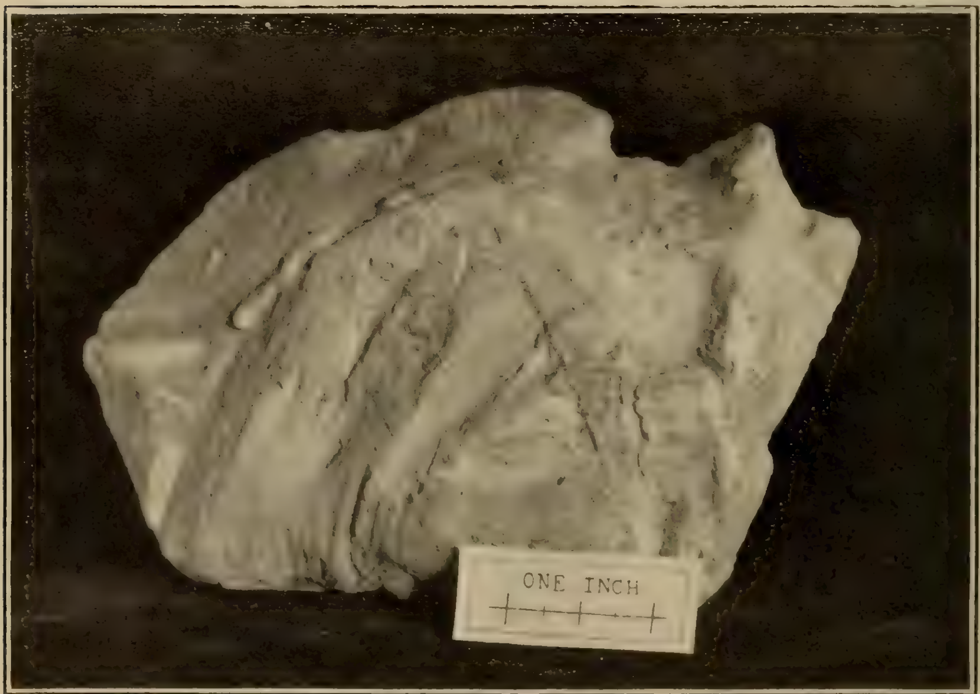

FIGURE 2.—SPALL FROM EDGE OF LIMESTONE BLOCK

Showing striation and pressure-cleavage of surficial layer of the limestone. Caney shales: Talihina, Oklahoma. Photo by Turpin

SLICKENSIDED AND STRIATED ORDOVICIAN LIMESTONE FRAGMENTS FROM TALIHINA, OKLAHOMA

In many cases the striations on the stones are surfaces of gliding in the shales grazing the side of the erratics. Thus in figure 1 of plate 23, the grooves and striæ spring out from the air, so to speak, the upper right-hand portion of the boulderet there shown having been covered at the time of striation by shale, in which the continuation of the striation must have taken place. The same characteristic is illustrated in the two grooves crossing the protuberance in the middle of the pitted pebble there shown. Indented pebbles of small size are common at Talihina and may be seen at the end of striated grooves on the larger blocks in a manner to show that the shoving of small pebbles past the larger stones in the interstitial and other movements of the contorted shales was a common method of producing the striæ and grooves. Figure 1, plate 24, shows one of these indented pebbles with a prominent groove or trail.

The plastic appearance of the surface of the limestone spall, figure 2, plate 24, shows how closely the matrix was pressed to the contour of the limestone, and the minute cleavage flakes of the limestone indicate that the surficial layer of the limestone was like many slickensides walls of faults in a thin zone of flowage, resulting in an imbricated cleavage, a feature unknown in the case of indurated rocks under glacial pressure.

Lenticular beds of limestone breccia occur in the railway cut at Talihina, and blocks of such beds occur weathered out on the surface. These blocks are, of course, not transported erratics. The brecciation of the limestone has apparently taken place *in situ* from crushing boulders and drawing out the crushed and comminuted mass into bedded form.

From the Choctaw fault, as shown on the State map of Oklahoma by Doctor Gould, southward to Talihina in the railway cut, the Caney shales are highly contorted and crushed.

Floating Ice in the Caney Shale Sea

As Mr. Taff points out, it is reasonable to consider the boulders and smaller stones as having been transported by some kind of ice action from the nearest known exposure of the Ordovician limestones in the Arbuckle Mountains. Floating ice is naturally suggested as the probable agency, notwithstanding that to have pan-ice at sealevel demands a greater degree of cold in this latitude than would be demanded for floating detached portions of mountain or plateau glaciers entering the sea in their zone of melting.

The Caney shales are known to be marine from the occurrence of the fossil shells in their basal portion, mentioned by Taff and described by Girty. At no part of the section north of Talihina did I observe beds resembling the tillite of typical Permian glacial formations.

Remarks on Carboniferous Climate

The occurrence of isolated boulders in the coal measures of North America has long been commented on and usually referred to the action of trees entangling boulders in their roots.[8] The abundant evidence of glaciation in the Permian and more remote periods now make it quite as reasonable to suppose that ice formed on the fresh waters of the Carboniferous, and the boulders of the Caney shale, regardless of their striæ, greatly strengthen this view. The Roxbury, Dighton, and other conglomerates of the Carbonic system in Massachusetts and Rhode Island, for which Professor Shaler postulated a glacial origin, appear to be torrential fan deposits laid down in a valley or valleys of aggradation at the side of a now eroded mountain mass. It may well be admitted that local valley glaciers were best calculated to produce the erosion of so much coarse granitic and quartzite material, the rolled state of boulders and pebbles being due to the action of glacio-natant streams. This view becomes a strong probability in the light of the remarkable breccia described by Messrs. Sayles and La Forge in the Boston area, where a bed at the top of the Roxbury conglomerate has all the mass characters of tillite, including a few discoveries of pebbles with markings which the authors named have not without many considerations in favor of their claims held to be of glacial origin. This presumable tillite bed is possibly of Permian age, but its association with the underlying conglomerates and similar thick water-worn conglomerates of known Carboniferous (Alleghany) age in the Narragansett area points to the correctness of Shaler's theory of the glacial origin of the conglomerates as a whole.

The modern amphibia, described as "cold-enduring," "patient of cold" by zoologists, underwent their first great development in the Carboniferous coal measures, and, if organic structure at so remote an epoch carries any significance as to climate, would lead us to expect that the Carboniferous climates of middle latitudes in the northern hemisphere were cool rather than warm. Ulrich[10] infers cool waters for the formation of marine black shales, but these are more in evidence in the Devonian.

Similarly in Europe, Julien has advocated the glacial origin of the coarse Carboniferous breccias of central France, and Kalkowsky has argued for the glacial origin of a pebbly shale in the Carboniferous rocks of the Frankenwald.[9]

In conclusion, it would seem possible to state that there is evidence for presuming that the Permian glacial period was preceded in the Carboniferous by a degree of cold permitting of floating ice in continental bodies of water and also in the sea in middle latitudes.

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[8] J. D. Dana: Manual of Geology, 4th ed., 1895, p. 664.
[9] See A. Geikie: Text-book of Geology, 4th ed., 1903, vol. ii, p. 1060, with references.
[10] Revision of Paleozoic Systems, pp. 352 to 361.

SOUTH DAKOTA AND NORTHEASTERN NEBRASKA

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PRE-WISCONSIN CHANNELS IN SOUTHEASTERN SOUTH DAKOTA AND NORTHEASTERN NEBRASKA[1]

BY J. E. TODD

(*Presented before the Society December 28, 1911*)

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GENERAL RELATIONS

Nearly 30 years ago it was discovered that in the early Pleistocene the master stream of the southeastern South Dakota region followed the valley of James River to its present mouth and then the Missouri below, and also that the present course of the Missouri above Yankton was outlined around the edge of the great ice-sheet as late as the Wisconsin stage.

Later studies made in preparing the Elk Point folio led the writer to the conclusion that there had been an earlier advance of the ice-sheet down the James River Valley at a time when the drainage level was about 100 feet higher than at present. Whether this was during the Kansan stage or the Iowan stage has not been determined, but probably it was during the Kansan. At that stage the Dakota lobe extended as far south as West Point, Nebraska, and the drainage from the west side

[1] Manuscript received by the Secretary of the Society January 10, 1912.

MAP OF PRE-WISCONSIN CHANNELS IN SOUTHEASTERN SOUTH DAKOTA AND NORTHEASTERN NEBRASKA

of the ice and of the country west flowed south through a channel passing near Creighton and Plainview into north fork of Elkhorn River. This old channel is now at an altitude of about 1,700 feet.

As the ice receded the main drainage outlet shifted eastward to a lower valley which passes near Hartington and Coleridge and connects with the valley of Logan Creek. This channel now has an altitude near 1,600 feet. Still later the drainage flowed along the present course of the Missouri, where the altitude is 1,200 feet. During the following interglacial epoch the channels about Elk Point were deepened about 100 feet—that is, nearly to their present level. At that time the valley of the Missouri River above Yankton was not in existence, and the Niobrara crossed the line of the present Missouri Valley east of Springfield, South Dakota, and entered the James River Valley a few miles north of Yankton. Ponca Creek also crossed the Missouri Valley and after a northward bend joined the old Niobrara near Springfield. A stream of similar size came past Fort Randall—whether from Pease Creek or Lake Andes has not been ascertained—passed several miles north of Greenwood, South Dakota, crossed Choteau Creek near its mouth, and joined Ponca Creek a few miles farther east.

The following facts are the evidence on which the above statements are based. The events are considered in chronologic order:

Channels of the Earlier Stage

THE CREIGHTON-PLAINVIEW CHANNEL

The principal evidences indicating that an ancient stream flowed past Creighton are the existence of a shallow valley connecting the upper portion of Verdigre and Bazile creeks with the upper portion of the north branch of the Elkhorn and the relations of this valley to the earlier drift. It is about a mile wide and 30 or 40 feet deep near Plainview, where it is least affected by erosion. It lies between the till-covered area to the northeast and the area of Tertiary sands to the southwest, on which there is but little drift. Traces of the channel northward have been obliterated by the erosion of present streams and by the effects of the Wisconsin ice.

THE HARTINGTON-COLERIDGE CHANNEL

That a stream flowed past Hartington and Coleridge is clearly indicated by the extensive gravel deposits shown on the map, plate 25. This gravel is first prominent a few miles east of Niobrara, Nebraska, 415 to 450 feet above the Missouri, and extending eastward across Bazile

FIGURE 1.—ERODED GRAVEL STRATUM IN BOTTOM OF ANCIENT CHANNEL
Looking east from point E on the map

FIGURE 2.—GRAVEL OVER VOLCANIC ASH STRATUM
Four miles south of Santee, Nebraska, looking west-southwest from point D. The shoulder marks the gravel stratum and the white spots in the road the volcanic ash

FIGURE 3.—VIEW EAST-NORTHEAST ACROSS THE HARTINGTON-COLERIDGE VALLEY

PRE-WISCONSIN CHANNELS IN NORTHEASTERN NEBRASKA

Creek to Weigand Creek. It forms a distinct terrace in places and there are also numerous gravel-topped knobs. South of Herrick a portion of it has either been let down by the undermining of the Tertiary sands below or been rearranged at a lower stage of the stream.

Some years ago[2] I regarded these gravels as remnants of a high terrace of the Missouri and not part of the Coleridge channel, an interpretation based on a record of elevation at Coleridge which was given 100 feet too high. Later when the gravel was traced past Hartington its relations were made clear. In places where the deposit has been cut through by later drainage the gravel remains as a cap on adjacent bluffs and knobs somewhat resembling moraines,[3] and they were so regarded by Aughey.[4] A view of such is given in figure 1, plate 26.

South of Santee agency the gravel is underlain by a stratum of volcanic ash several feet thick, which lies on laminated clay containing fresh-water shells.[5]

This ash is shown in figure 2, plate 26, from a photograph taken at D on the map, plate 25.

At Coleridge, where the Coleridge-Hartington channel passes through the divide at an altitude of 1,550 feet, it is represented by a valley 3 to 4 miles wide, with its floor about 150 feet below the adjoining loess plain. This wide valley includes two or three subordinate channels or intervales 20 to 30 feet deep, with broad, flat ridges intervening which may have been bars or islands in the ancient streams. A view across the valley at Coleridge is given in figure 3, plate 26. Some features of these old channel gravels suggest that they may have had a similar history to that of the Aftonian gravels, lately described by Professor Shimek,[6] as extensively developed in western Iowa. No correlation can be offered, but the difference in altitude appears to show that they are not contemporaneous. It is likely that at the time of deposition of the gravels in the Coleridge-Hartington channel the drainage to the south was farther west than the present Missouri River, and probably passed into a lake or series of lakes in eastern Nebraska which may transiently have drained southward into Big Blue River.[7] It seems not impossible that both formations are to be connected with the Kansan ice-sheet, and that the thin deposit of till, which is found overlying the Aftonian in places, may belong to the

[2] Bull. U. S. Geol. Survey, No. 158.
[3] See also U. S. Geol. Survey, Geol. Atlas U. S., Elk Point folio, No. 156, p. 5.
[4] Physical Geography and Geology of Nebraska, p. 256.
[5] Bull. U. S. Geol. Survey, No. 158, p. 70.
[6] Iowa Geol. Survey Reports, vol. 20, and Bull. Geol. Soc. America, vol. 21, p. 81.
[7] See Trans. Kansas Acad. Sci., vol. 22, p. 107.

Iowan stage, the occurrence of which is so problematical, especially in western Iowa.

Channels of the later Stage

GENERAL CONDITIONS

As already stated, the other channels considered belong to the drainage of a later epoch when the conditions were considerably changed. The Kansan ice had disappeared and the larger streams were running much as before its advent. For convenience these channels are named after present streams which occupy portions of the old channels. They will be described in the order of their size, namely, the Niobrara, Ponca, Mosquito, and Choteau.

THE ANCIENT NIOBRARA

There will here be considered only the old course from Niobrara, Nebraska, to the James. Presumably its former course elsewhere was the same as that of the present stream.

The reasons for believing that the Niobrara formerly crossed the line of the present Missouri Valley east of Springfield and flowed over the divide at Tabor and down Beaver Creek to the James are briefly as follows:

1. The most obvious evidence is the topography, for the general slopes from the south as well as from the north converge toward the old valley, which has now an altitude of about 1,350 feet. The highland west of Yankton rises to altitudes more than 1,500 feet and declines regularly toward the old Niobrara Valley, and the slope is deeply covered with drift clays. To the south lies the gorge of the Missouri, much younger in appearance and exposing older rocks everywhere.

2. There are continuous chalk cliffs on both sides of the Missouri above Yankton excepting for an interval filled with stream deposits, extending from a point below Springfield to a little east of Bonhomme. The west bank is well defined, but the east bank is less clear, perhaps partly on account of a thicker deposit of till on that side. The interval is about 3 miles wide, but as the stream may cut the bank obliquely the minimum width is somewhat less. A section of the old river channel deposit in this gap as exposed in a perpendicular cliff facing the river is as follows:

	Feet
Black soil	2
Dark buff loess-like silt	12
Darker soil-like layer	1
Typical yellowish till	58

the last extending down to level of bottom land, which is about 10 feet above the Missouri River.

Three or four wells along the line of this valley from Missouri River to Tabor show that the older rocks are about 100 feet below the surface, which is at an altitude a little less than 1,350 feet.

3. Another evidence of minor importance is the occurrence of boulders of green quartzite of the Loup Fork group at the south end of a gravelly ridge north of the junction of Beaver Creek and James River. The source of these boulders probably is to the west, for green quartzite is extensively exposed west of Niobrara and, on the other hand, it is absent to the north.

THE ANCIENT PONCA

The evidence of a former channel of Ponca Creek north of the Missouri is very similar to that already given for the old Niobrara. Its course was from section 36, township 93 north, range 62 west, northeast past Perkins nearly to the valley of Emmanuel Creek, with which it swings around south for some distance. It left that valley west of Springfield station and finally entered the Niobrara near where Emmanuel Creek now joins the Missouri.

1. The topographic evidence of this channel is similar to that of the Niobrara, especially in the fact that the general surface of the region slopes toward it rather than toward the Missouri. The intervening divide is about 500 feet above the Missouri, while the ancient Ponca channel is less than 200 feet above.

2. There are old stream deposits, notably at a locality just east of a high hill, on the east side of the junction of Choteau Creek and the Missouri. Here there is quite a clear cross-section of the old stream deposits about a half mile wide, with its bottom about 35 feet above the Missouri River. The east bank of the old channel is well marked at this place, being partly excavated in chalk; the west bank is obscured by the erosion of recent streams. The channel is filled with 10 to 15 feet of gravel overlain with sand and clay and a capping of loam, which extends to a height 140 to 150 feet above the river.

A ravine cutting the side of the old channel deposit a few rods form the river has the following section:

	Feet
Fine stratified sand and clay	24
Coarse gravel, with no northern boulders	4
Pea gravel and sand	2
Chalk, bluish below	6

The top of the chalk is about 30 feet above the river. On the opposite side of the same creek the chalk rises about 65 feet above the river, while

a half a mile farther northeast, in the bottom of a watercourse, a cut bank showed 20 feet of gravel.

There are deep wells in southwest one-quarter of section 21, northeast one-quarter and northwest one-quarter of section 28, and northeast one-quarter of section 29, township 93 north, range 61 west, which show much sand, while farther east deep wells show only chalk. Northwest of Springfield, where the broad valley in which Perkins is located merges into Emmanuel Creek Valley, the bluffs on the west side are less abrupt, and they are composed of till above and of sand below, while on the east side the chalk bluffs are prominent. Farther south, in southeast one-quarter of section 21, township 93 north, range 60 west, an isolated hill near the creek shows chalk extending high up its east side, while its west side is a thick mass of sand. Below this place there are chalk cliffs on both sides of the creek valley, and opposite Springfield depot the chalk cliffs rise 90 feet above the creek, or to an altitude of 1,300 feet. About half a mile west of Springfield the surface of the chalk passes under a thick deposit of sand and gravel. Springs at an altitude of about 1,245 feet probably mark the bottom of the sand in this locality. The sand-filled valley was traced only a little farther south, and the point where it crosses the chalk cliffs adjoining the Missouri Valley was not ascertained.

THE ANCIENT MOSQUITO

The ancient Mosquito Creek flowed through the fertile valley north of Greenwood and along the upper portion of Slaughter Creek. This valley and the low divide separating it from the Missouri River was first[8] regarded by the writer as forming a high terrace of the Missouri, but later observations have led to the view that it was an old channel.

1. The topographic evidence of the Mosquito Creek channel has not been obscured by glacial action, as in the case of some of the other channels, because it lies outside of the outermost moraine. On the other hand, however, the divide between it and the Missouri is less prominent, only rising about 100 feet above the old channel, or about 300 above the Missouri. The channel reaches the edge of the Missouri Valley near latitude 40 degrees in a col about 190 feet higher than the river. It follows Mosquito Creek to the junction with Slaughter Creek, then continues southeast through a slough to the lower course of Cold Springs Creek, which has the same direction, and finally it opens into the bottom lands of the Missouri. Instead, however, of uniting with the present river channel it extends across the lowlands to Choteau Creek Valley and, crossing that valley near its mouth, passes up a small tributary

[8] Bull. U. S. Geol. Survey, No. 158, p. 132, Washington, 1886.

FIGURE 1.—VIEW ACROSS THE OLD CHANNEL BETWEEN MOSQUITO AND COLD SPRINGS CREEKS

South 48 degrees west from point A on the map

FIGURE 2.—ERODED ALLUVIUM OF THE ANCIENT MOSQUITO CHANNEL, WITH THE MISSOURI IN THE BACKGROUND

View southeast from C on the map

PRE-WISCONSIN CHANNELS IN SOUTHEASTERN SOUTH DAKOTA

from the east to join the channel of the old Ponca Creek about 3 miles east of Choteau Creek.

A view across the Mosquito Valley from the northeast is given in figure 2, plate 27, from point A on the map, plate 25.

2. Geological evidence is as follows:

Slaughter Creek shows chalk and shale throughout its southwesterly course as far up as the old Mosquito Valley, where the shale gives place to alluvial material.

Near the southwest corner of section 2, township 93 north, range 63 west, or about one and a half miles west of the point where Cold Springs Creek comes out on the bottom lands (point B on the map, plate 25), there is a fine spring in a deep ravine about 10 rods back from the face of the chalk wall. The sides of this ravine show that a channel has been cut 25 to 30 feet into the shale and underlying chalk. This is inferred from the level of the spring, which is about 60 feet above the bottom land opposite. The channel, which merges into the river valley about 20 rods farther east, is filled mainly with silt closely resembling loess and showing but little trace of stratification. It contains widely scattered pebbles. Probably the lower part is sand, although no clear exposure was found. The spring is highly charged with iron.

Chalk banks appear along Cold Springs Creek north of the line of the north bank of this old channel, which may be a third of a mile in width. Eastward from this point for several miles the channel is marked by numerous knolls which have been carved out of the silt which originally filled it. A view of some of these is given in figure 2, plate 27, from a photograph taken at point C on map, plate 25.

The crossing of Choteau Creek Valley by the old Mosquito Creek channel is not clearly marked, but the valley of a small eastern tributary of the Choteau shows that the chalk has been removed to the proper depth in a valley north of a high hill just east of the mouth of Choteau Creek. This feature is indicated on the map, plate 25.

THE ANCIENT CHOTEAU

The course of the ancient channel of Choteau Creek has not been traced so clearly as the others and the principal evidence is topographic. Inside the principal moraine, which here lies on a high ridge of pre-Glacial or at least pre-Wisconsin age, there is a practically continuous depression extending from the upper valley of Pease Creek across the southern end of Lake Andes and along the middle portion of Choteau Creek, running east of that stream for a few miles above its junction with the Dry Choteau. Below that place it may have run southeast to

the Ponca, as indicated on the map. Along this course the altitude is from 1,400 to 1,450 feet, and there is no swell rising more than 20 or 30 feet above the general slope. Doubtless the configuration resulted from the work of glaciers which overrode the region. It is reasonable to believe that the upper part of Platte Creek from as far north as White Lake may have all drained through this channel in the earlier and later portions of the Kansan stage of the ice. However, no direct evidences of this was obtained from excavations or deposits. The profile of this valley corresponds with the slope of the streams just described, allowing for about 100 feet deepening during the interglacial epoch following the Kansan or pre-Wisconsin stage, as found in the case of the James and Vermilion. Its level corresponds fairly well with that of the Hartington-Coleridge and later channels, which were occupied by the peripheral waters of the Kansan stage.

Conclusions

It is believed that the evidence presented above sustains the interpretation of events as outlined at the beginning of this paper. There may also be added with somewhat less confidence the following inferences:

1. The edge of the pre-Wisconsin ice-sheet did not extend so far west as that of the Wisconsin sheet, although it reached considerably farther south.

2. The Wisconsin ice did not reach as far south as the southern edge of the earlier ice-sheet because the river valleys, particularly of the Niobrara and James, were then much deeper and therefore a much more serious obstruction to extension in that direction. Possibly, also, the later ice may have been thinner or of higher temperature.

3. On the west and southwest, on the contrary, the marginal drainage may have flowed just beyond the edge of the earlier ice, and by its interglacial erosion removed obstacles, so that the later ice filling the new valley advanced several miles farther west than the earlier ice had done. As a result the Missouri, the master stream of the time, then located its present valley, which is farther west than the one it occupied in the pre-Wisconsin time. This was done in a way very similar to the shifting of the drainage from the ancient Ponca Creek and ancient Niobrara River to the present valley of the Missouri, as stated above and shown on the map, plate 25.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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COVEY HILL REVISITED[1]

BY J. W. SPENCER

(Presented before the Society December 27, 1911)

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Detailed Features of Covey Hill Gulf

This locality has been regarded as a critical point in the study of glacial dams. It has been most fully described by Prof. J. B. Woodworth.[2]

The summit of the hill is 1 mile north of the international boundary line and some 20 miles west of Lake Champlain. It is a flattened ridge 3 or 4 miles long, rising on the floor of the northeastern angle of the Adirondack plateau. The highest point is 1,113 feet above the sea. Immediately southward is a flat depression, a mile in width, reduced in part to an elevation of 1,025 feet. Both north and south of the depression steps of rock rise abruptly. The outlying Covey Hill is like eminences observable on dissected tablelands, best seen outside of drift regions, where the local drainage, descending both sides of spurs, produces depressions which eventually dissect the plateaus into separated flats or ridges. This was evidently the pre-Glacial history of Covey Hill. The hill slopes rapidly northward, descending to plains 300 to 400 feet above tide.

The promontory is capped with Potsdam sandstone, covered by a thin layer of drift, but this has been entirely swept off the rock surface of

[1] Manuscript received by the Secretary of the Society January 31, 1912.

[2] Ancient water levels of the Champlain and Hudson valleys. Bull. 84, N. Y. State Museum, 1905, pp. 161-164, 173-174.

the spillway or broad channel mentioned, now covered by a young growth of trees succeeding great forest fires.

Its most striking feature is known as "The Gulf." This is a canyon with vertical walls 120 feet high, cut out of the sandstone floor of an outer valley at 915 feet above sealevel, which has a length of nearly a mile, thus strongly marking the former level of some lake beyond. This outer valley heads in an amphitheater with vertical walls 50 feet high. In it nestles a small, shallow lake (at 915 feet), barricaded by vegetable growth (*a* on map).

The Gulf proper in this outer valley begins as a narrow chasm 10 or 20 feet wide. Farther on it widens abruptly to 50 feet or more. Con-

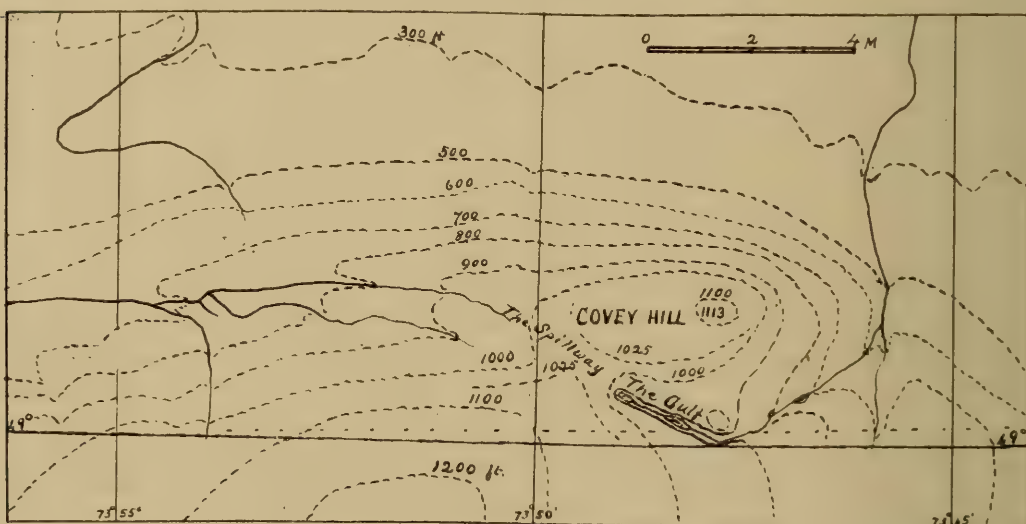

FIGURE 1.—*Sketch Map of Covey Hill*

tinuing downward, and after another widening, it becomes a canyon 300 to 400 feet broad and 125 feet deep. The vertical walls are in places faced by steps. In the descent the bed of the stream slopes rapidly, but not precipitously, and is covered with sunken blocks of sandstone, appearing to have been undermined, thus making the loose stones dip downward. They are not transported blocks. Where the gorge is wider the talus of broken rocks is abundant, and in one place it has crossed the channel, leaving a dry basin behind it, as the drainage is underneath. Even in the dry season considerable water is flowing here, but above this point the streams are entirely through crevices, so that very little surface water is seen. During rainy periods, or the time of the melting of the snows, the torrent is said to have a depth of 3 feet. The strata are

strongly dissected by joints, which are opened for a width of 6 to 12 or even 24 inches.

The lower part of the Gulf contains a lakelet some 900 feet long and 200 feet wide. Its elevation is 800 feet above the sea. Its depth is great, as all the abundant talus, cleaving off the walls, is swallowed up by the waters. Its depth is probably 50 feet to the level of a lower water plane (at about 750 feet). Immediately beyond the lake the vertical walls are abruptly replaced by a V-shaped gorge, with the falling talus barricading the lake. This lower section has an older and distinct history.

Covey Gulf is relatively a very small trench compared with the channel floor, of perhaps a mile in width, into which it is cut. Currents which swept the drift from the surface of the outer channel could not possibly have been confined within the narrow chasm, which shows a continuous growth from its head.

The features show that the Gulf was made by a small stream, with its broadening due to frost action, the drainage basin having perhaps been no larger than that of the plateau above during two or more episodes, when the baselevel below was stationary as at 915 feet, thus facilitating the widening of the canyon. Indeed, the disintegration of the sandstone has been very rapid. In another locality I found that a small waterfall had been cutting back into the same kind of rock at the rate of about a foot a year, not to speak of the frost action.

The terraces mark the abrupt lowering of the water in the higher part of the gulf, the most important uniting to form the floor of the outer gorge. Unlike the sharp V-shaped upper portion of the main gulf, the head of the outer gorge is somewhat rounded, a form apparently due to the three or more streams which enter about its upper end. This feature is common where streams unite to form coves in hillsides. The same might be due to waterfalls, as in this case it is unlike the sharp V-shaped head of the inner gorge of only a few feet in width, but it is improbable that different forces make the upper ends of the two gorges, and the multiplicity of the streams would account for the rounded form of the end of one of them.

The pond in the inner gorge is situated at a long distance from its head, so that there seems to be no pronounced connection between it and any cascade or rapids. The pond in the outer and shallower gorge is drained by underground channels. About its lower end are slabs of rock, absent from its upper margin. Their occurrence is easily explained, as being due to loose blocks frozen in the ice and drifting down with the

spring floods. This is a very common feature about small lakes, where boulder beaches are raised several feet on the leeward side.

Indeed, some shallow rock basins are due to ice expansion in crevices and subsequent lifting of the loosened blocks, according to the theory of K. Loranges.[3] The creviced structure is favorable for this result, especially during changing levels of water, due to floods or the impeding or opening of the underground drainage, which was observed as obtaining. The theory of a pool beneath falls does not seem applicable to the formation of a pond situated at a distance from the head of the gorge.

The time of the broad flood, sweeping through the depression behind Covey Hill, was marked by the drainage from a large body of water, but its duration may not have been long. Indeed, the conditions could only permit of a relatively small snout of a glacier impinging against the northern side of Covey Hill, with open water on the western side and a district free of ice on the eastern. At the later date of the formation of the Gulf the glacier was situated much farther away, as shown by the traces of terraces on the northwestern side of the hill, being the same as mentioned by Woodworth, at a corrected elevation of 915 feet above the sea, corresponding to the floor of the outer valley at the head of the Gulf proper. These features preclude the idea of a sweeping supply of water from a glacial dam (which could not have been less than 1,025 feet above the present sealevel) having formed the Gulf.

Origin of Covey Hill Gulf

From observations in the field the conviction left is that Covey Gulf was formed by the local drainage only since the time when the glaciers left the upper part of the hill. What length of time has elapsed since the ice epoch in this region? Difficulty is found in following and identifying the old shorelines north of the Adirondacks, although fragments of beaches and deltas may be frequently seen. Their characteristics here are unlike those of the Iroquois beach south of Watertown. After allowing for post-Glacial deformation, the height of the Covey Hill spillway appears to be 50 feet above the plane of Lake Iroquois, the outlet of which was by the Mohawk Valley. Accordingly, with our present knowledge, it would seem that the floods sweeping the channel came from a glacial lake of somewhat earlier date than the Iroquois beach, which bounded

[3] Geologiska Fœreningens, Stockholm, 1874-1875, p. 343. My attention was called to this theory for explaining certain shallow rock basins by Professor Brœgger, who placed high value on it.

the lake of the same name. Indeed, at the head of Lake Ontario is the Bell terrace, with which this spillway might be correlated if the body of water were as great as that of Lake Iroquois.

The Reputed marine Beach of Covey Hill

One of the lower beaches on the northern side of Covey Hill occurs at 523 feet above tide. This is the corrected height of the beach hitherto mentioned at 450 feet, as pointed out by Fairchild, with the new measurement taken from a Canadian topographic map (Chateaugay sheet). The beach referred to has been accepted by Woodworth, on the suggestion of Gilbert, as the upper limit of marine beaches, and later insisted on by Fairchild. Of this no evidence has been offered beyond the assumption that it was at the height of marine deposits elsewhere, and on account of the coarseness of the material that it could not be expected to preserve the shells, of which none have been found. But on making allowance for post-Glacial deformation this shoreline is found to be at least 160 feet above the marine deposits a short distance southeastward, near Moores Junction, 340 feet (Woodworth). The assumption that shells should not be expected in the ill-assorted sand, gravel, and larger stones is not supported, for east of Morrisburg, north of the Saint Lawrence River, coarse gravels, with stones from 12 to 20 inches in diameter, have their interspaces filled with *Saxicava* and other shells. These indicate that if the terraces of Covey Hill had been marine there was no reason why the shells should not have been preserved.

The beach occurring on the northern flank of Covey Hill, at 523 feet, is very strong, with much coarse materials. Crossing the plain country for 40 miles to Montreal, marine terraces are there found, but at lower elevations, except one deposit of different character. This is composed of free sand with marine shells at an altitude of 575 feet above the sea, which corresponds to Dawson's locality at 560 (corrected to 572 feet for change of datum from lake Saint Peter to mean tide at New York). But it is at a different locality, where I have myself collected the shells. These marine deposits are covered by several feet of an earthy mantle containing stones. On the surface there is no beach structure whatever, like that of the great shoreline of Covey Hill, at a lower altitude.

As no calculations have been made from the earth movements showing that the Covey Hill 523-foot beach was formed at sealevel; as no marine shells have been found in it; as it is higher than the marine ter-

races at Montreal, and as it cannot be correlated with the upper marine sands there situated, which are covered by a later deposit showing no beach structure at the surface, there appears to be no ground for assuming this great beach of Covey Hill to be of marine origin.

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HANGING VALLEYS AND THEIR PRE-GLACIAL EQUIVALENTS IN NEW YORK [1]

BY J. W. SPENCER

(*Read before the Society December 29, 1911*)

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HISTORICAL NOTES ON THE RISE OF OUR LACUSTRINE GEOLOGY

The investigation of the pre-Glacial valleys of the Finger Lakes, or of the Iroquoian Lakes, as designated by Mr. John Corbitt,[2] was a natural sequel to the study of the origin of the basins of the Great Lakes. As few persons are now remaining familiar with the beginnings of the researches into the history of the lakes, some account of these may be introduced. A generation ago the most popular explanation of their origin was that assigning to glaciers the work of having excavated the basins. This theory was based on the opinion of Sir A. Ramsay, of the Geological Survey of Great Britain, who said that "the lake basins could only, I believe, have been scooped out by true continental glacier ice like that of Greenland," a belief based on the one fact that the lakes occur in ice-worn regions. The same conjecture was made in America by Prof.

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[1] Manuscript received by the Secretary of the Society January 31, 1912.
[2] Editor of the Schuyler County Chronicle, Watkins, N. Y.

J. S. Newbury, who, to some extent, modified this view by his recognition of a buried channel under Lake Erie at Cleveland.

Discussion concerning the Finger Lakes

At this stage my studies bearing on the origin of the basins of the Great Lakes were begun by investigations of the buried valleys and submerged escarpments. For this work I was inspired by Prof. J. P. Lesley, whose interest was aroused by observations of my own, which he urged should be published at once.[3] Even without the cause of the barrier to the Ontario basin being discovered, he considered that the facts, then made known, "disembarrassed us of the chief difficulty of our best preserved water system of the North,"[4] and gave the *coup de grace* to the belief in the glacial origin of our lake basins. Nor was he alone of this opinion, for Prof. James Geikie then wrote: "I have always had misgivings as to the glacial erosion of the Great Lakes. . . . Possibly those who have upheld that view will now give in. Your facts seem to me, at least, very convincing. I never could understand how those Great Lakes of yours could have been ground out of ice."

My first acquaintance with Mr. G. K. Gilbert was when he wrote concerning this first publication, saying: "The problem of the origin of the basin of the Great Lakes has always had a great attraction for me. Had I been able to understand its solution, my working hypothesis would have been that which you have demonstrated so thoroughly. . . . The matter has certainly never received a demonstration until your paper appeared," etcetera.

Several years elapsed before substantial progress was made by my showing that the rock barrier, in addition to the drift obstruction, was due to the post-Glacial warping of the region, and that the pre-Glacial outlet of Lake Huron was through Georgian Bay and a now buried valley into the Ontario basin;[5] also that there is a buried pre-Glacial channel between the Erie and the Ontario basins sufficiently deep to have drained the upper basin.[6] As the result of all these discoveries, Prof. T. G. Bonney has declared the researches epoch-making. Nevertheless, one or two, notably Prof. R. S. Tarr, attempted to revive the ancient faith in glacial erosion of lake basins.

At first Professor Tarr argued against ice erosion,[7] but the following

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[3] Proc. American Phil. Soc., vol. 19, 1881, pp. 300-337.

[4] Rept. Q4, Geol. Surv. Pennsylvania, 1881, pp. 357-404.

[5] Proc. American Asso. Adv. Sci., Cleveland Meeting, 1888.

[6] "Evolution of the Falls of Niagara." Geol. Surv. Canada, 1907, chapters 35-37. Here are also given references to the original publications.

[7] American Geologist, vol. 12, 1893, pp. 147-152.

year he recanted. Without inquiring what evidence had been found by borings, or how much post-Glacial tilting had occurred, or if the hanging valleys had buried predecessors, he declared Cayuga Lake to be a rock basin. His dictum was based only on the occurrence of the modern hanging valleys and their waterfalls. On the strength of this one feature he says: "As the tributaries of Cayuga River prove the rock basin origin of Lake Cayuga, so also the Cayuga tributary to the Ontario stream indicates that Lake Ontario is also rock basin.[8] To this I replied at the time.[9] Later he says: "I am more than fully convinced that the two larger lakes (Cayuga and Seneca) are of the nature of rock basins." [10]

That he had not made an investigation of the pre-Glacial equivalents of the hanging valleys is shown by his own words, writing ten years later: "Though the existence of older gorges have been determined, in one or two cases their abundance and their relationship to mature hanging valleys were not understood;" and "The theory of glacial erosion has been held as the most rational explanation of the phenomena of the Finger Lakes." [11] At this time (1904) he published a reversal of this last conl clusion, saying: "Until the facts opposing glacial erosion are explained, or until the possibility of the rejuvination theory is eliminated, the current theory of glacial erosion recently revived (largely by Tarr himself) can not be established." [12] Again Tarr wrote: "The fact that I have been quoted as an opponent of the glacial erosion, which has not been the case," etcetera; but he mentioned the occurrence of decayed rock at Ithaca in evidence against the late glacial erosion of the Wisconsin epoch. Now he falls back on an earlier period, saying: "There still remains some evidence opposing glacial erosion, but none opposing erosion by an earlier advance [of ice], unless the fact that no deposit of an earlier ice advance are found in this region is opposing evidence."[13] Thus the author still clings to his theory by falling back on negative evidence in an earlier period, while abandoning his theory as inapplicable to the work of the later Glacial period. Even the occurrence of one or two concordant tributaries to the Finger Lakes, as mentioned by Tarr himself, should not have been passed over, as these in themselves cast doubt on the theory of glacial erosion, not to speak of the buried outlet at the northern end of

[8] Bull. Geol. Soc. America, vol. 5, 1894, pp. 339-356.

[9] American Geologist, vol. 14, 1894, pp. 134-135.

[10] See his Physical Geography.

[11] American Geologist, vol. 33, 1904, pp. 277-291.

[12] Journal of Geology, Vol. 14, 1906, pp. 18-21.

[13] Ibid.

Cayuga Lake, or of the northward warping of the earth's crust in that region, which show that Cayuga Lake is not rock basin.

Hanging Valley of Taughannock Falls

I visited Taughannock Falls, in the most important hanging valley adjacent to Cayuga Lake. The gorge is excavated out of the jointed Devonian shales favorable for the production of vertical walls. Immediately north of this stream is a partly reopened buried valley, described by Prof. James Hall in 1842. It is plain that this was the course of the ancient drainage of the plateau, which becoming obstructed during the glacial period was diverted to the present course of Taughannock Falls.

Reversals of Drainage at the Head of Seneca Valley and its Excavation

Seneca Lake is even more interesting. In ascending the valley from the lake to the summit, at Horseheads (from 443 to 914 feet above the sea), a deep valley (more than 158 feet) has been found by borings. At Horseheads these do not reach to bedrock, but show the valley floor to be less than 756 feet above tide. If only 75 feet of the drift filling were removed (at A-B on figure 1) the Chemung River, with the Cohocton, would be turned northeastward in a broad valley and discharge through Seneca Lake, while the present course is along a narrow rock-bound channel to the Susquehanna. Originally the Cohocton and other streams flowed southward at a high level, but in the early history of the Seneca Valley the north-bound waters encroached on the plateau and robbed the south-flowing streams. Then the drainage through Seneca Valley was increased 12 or 15 fold, with a deep channel developing more rapidly than the hill on either side could be worn down by their restricted drainage. With the deposits of the glacial period a barrier was formed which turned the Chemung and associated streams southward from Seneca Valley.

A word may be added with regard to Seneca Lake. The deepest sounding is 612 feet, but a boring at the head of the lake was said to reach 1,000 feet below the surface. This well has been cited as the evidence of the depth of the drift. Concerning it, Mr. John Clute, the manager of the salt company, who caused the boring to be made, stated to me that it was in quicksand, but no detailed record or samples were kept. The salt wells on the side of the valley require to be cased to a depth of 1,100 feet on account of the character of the rock. These facts throw doubt on the reported depth of the drift found in the well.

From the many borings, Mr. Clute found that there is a bed of pure salt 200 feet thick, and also other beds of salt and shale, so that the whole series is 900 feet thick. The formation extends northward and underlies the widest part of Seneca Lake, rising at the rate of nearly 25

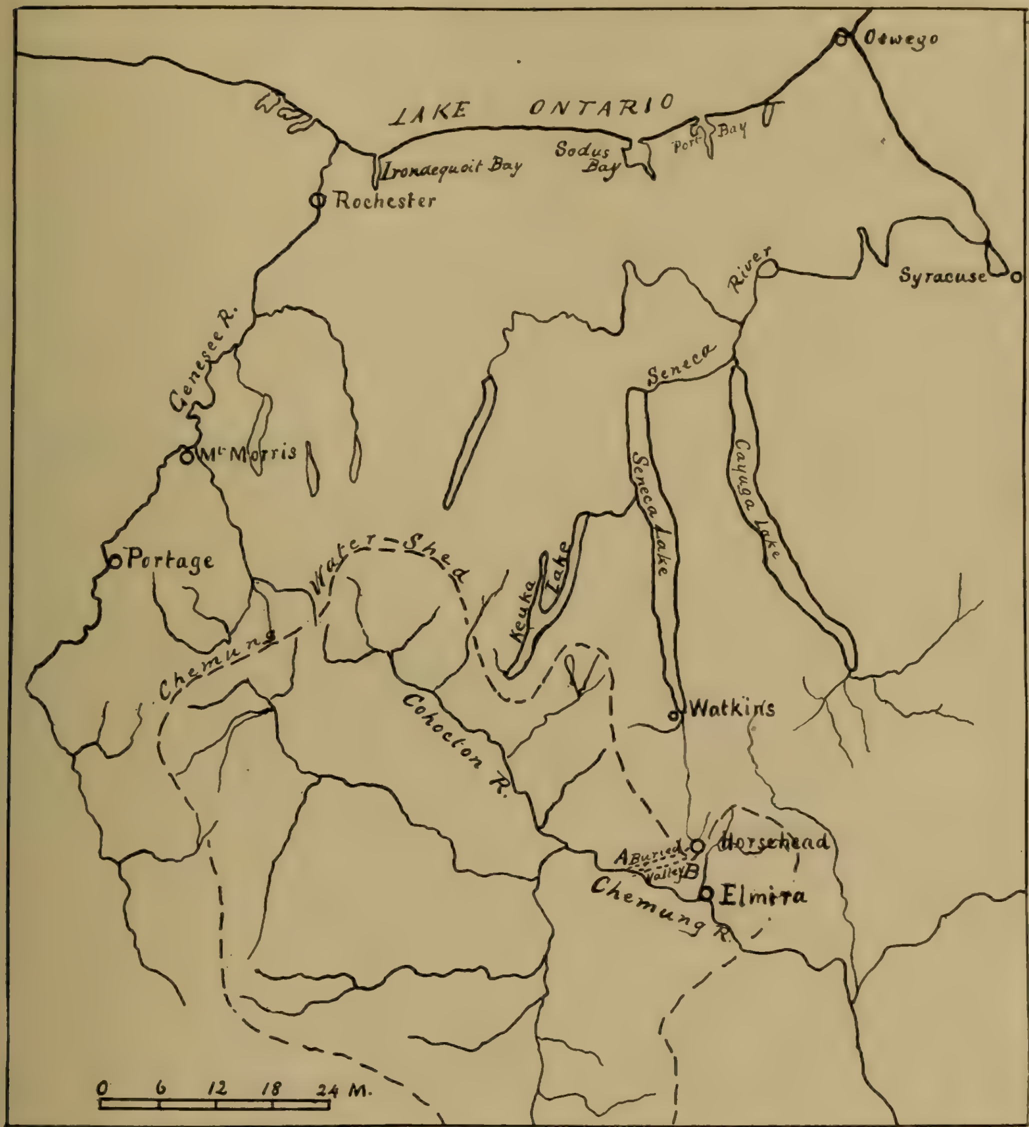

Figure 1.—*Sketch Map of Region adjacent to Seneca and Cayuga Lakes* Showing the pre-Glacial drainage basins

feet per mile. The overlying strata are there broken and undulating, as if a local subsidence had occurred.

From the absence of a rock barrier as found by borings and on account of the post-Glacial northward warping, it appears that Cayuga Lake is not a rock basin; but no borings have been made in the line of Seneca

Lake showing the maximum depth of the drift filling, beyond the fact that it is more than 250 feet at the side of the valley. Its direction leads

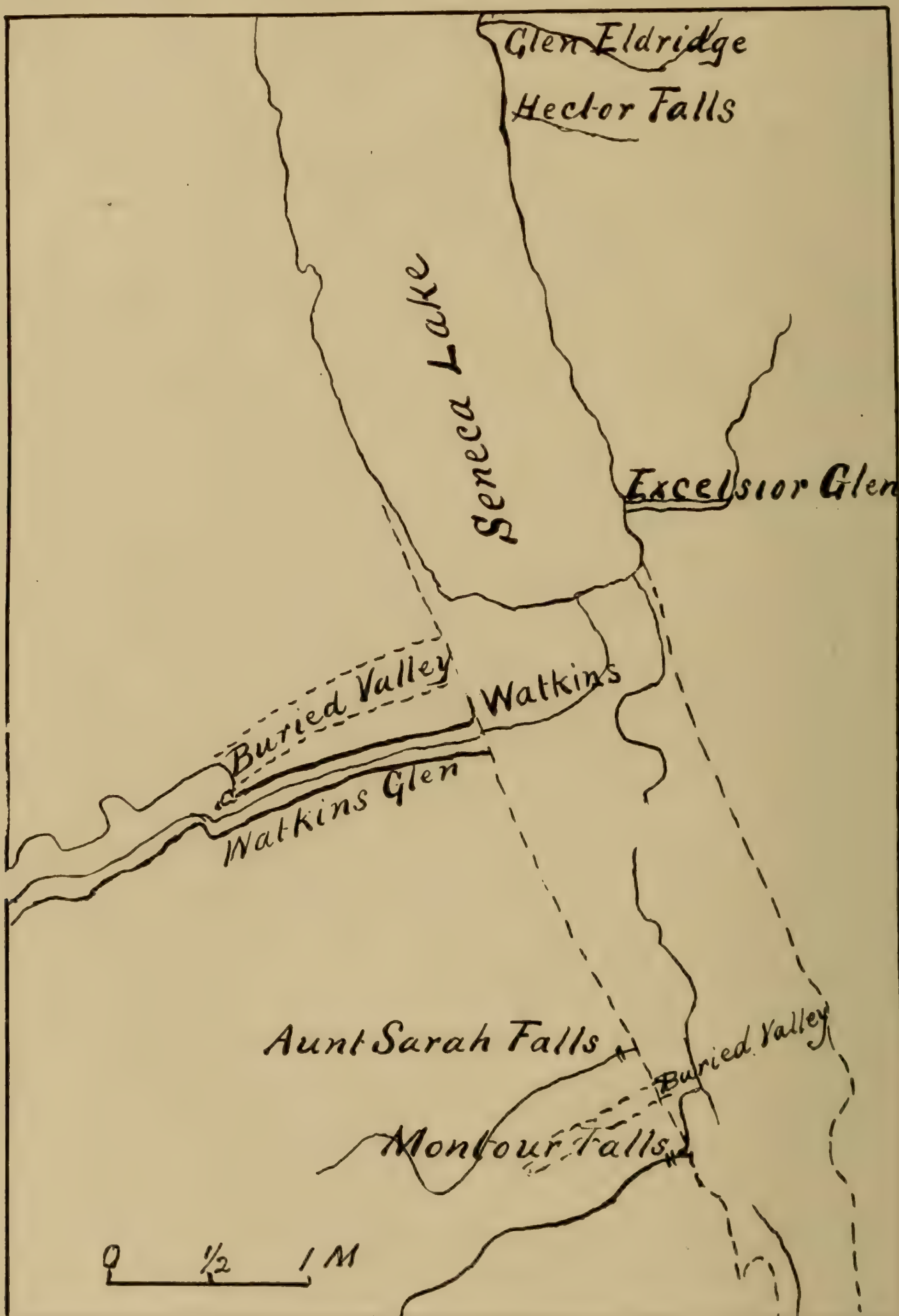

FIGURE 2.—*Sketch Map at Head of Seneca Lake*

to Sodus Bay, which is manifestly a continuation of the valley of Seneca Lake, excavated through the hard strata into soft shales, so that there

should be no conjecture that Seneca Lake is a rock basin until such be proved.

Watkins Glen and its pre-Glacial Equivalent

However, if further investigations should show that Seneca Lake (the bottom of which is above that of Lake Ontario) is partly barricaded by rock, there would be strong suspicion that its basin was partly due to the sinking of the floor, owing to solution and removal of underlying salt, which explanation is not needed for Cayuga Lake, nor indeed is it needed here on account of known facts.

The high country back of Watkins Glen calls for an ancient drainage in the direction of that of the present time, but a passing visit would not leave the impression that such did formerly exist. The rock-walled glen is 1.38 miles in length, rising from 443 feet above the sea to 850 feet beneath the railway bridge (which is 1,015 feet above tide). It is a narrow fissure in the jointed Devonian shales which has been opened by the modern streams. Immediately above the bridge is an enlarged embayment (see figure 2), the northern side and eastern end of which are bounded by banks of drift. Above the bridge the rocky glen becomes a wider valley excavated out of drift, with the rock appearing at only a few points. Here is the great pre-Glacial valley of the district. To the north of the rock-bound glen the ancient valley is not open, but it is found by borings, which reach to 150 feet or more in depth without encountering the bedrock (Corbitt). The reopened cove above the railway bridge is a repetition of the features of the Whirlpool at Niagara.

Hanging Valleys at the Head of Seneca Lake and their pre-Glacial Equivalents

Three miles up the Seneca Valley is Montour Falls cascading over the rocky side of the trunk valley. Its small stream has not yet cut a gorge more than 25 feet in length. Half a mile to the north is Aunt Sarahs Fall (named after an Indian woman), also descending over the side of the valley. Between these falls is a dry valley in drift heading in the higher country. Along its course, at three-quarters of a mile from its mouth, Mr. Corbitt and others sunk a well in drift to a depth of 150 feet without reaching rock. The pre-Glacial representative of both of the modern hanging valleys is seen in dry valley between them.

At 300 feet above the eastern side of the lake is a peneplain. Here Hector Falls, descending in cascades, has receded only a few feet in the

rock, but Glen Eldridge is a deeper trench. To the south is Excelsior Glen, with a much longer gorge, although the stream is insignificant. This glen owes its size to the reopening of a buried valley, where the stream in part flows over the rocky walls of the old valley. Tug, Hector, and Texas valleys naturally meet in one, and these in ancient times probably came down the now partly reopened valley near Excelsior Glen, as pointed out by Mr. Corbitt.

Hanging Valleys here no Proof of glacial Excavation

Thus all of the hanging valleys about the head of Seneca Lake are found to have corresponding ones buried by the drift during the different Glacial periods, and do not require any one to evoke the glacial erosion

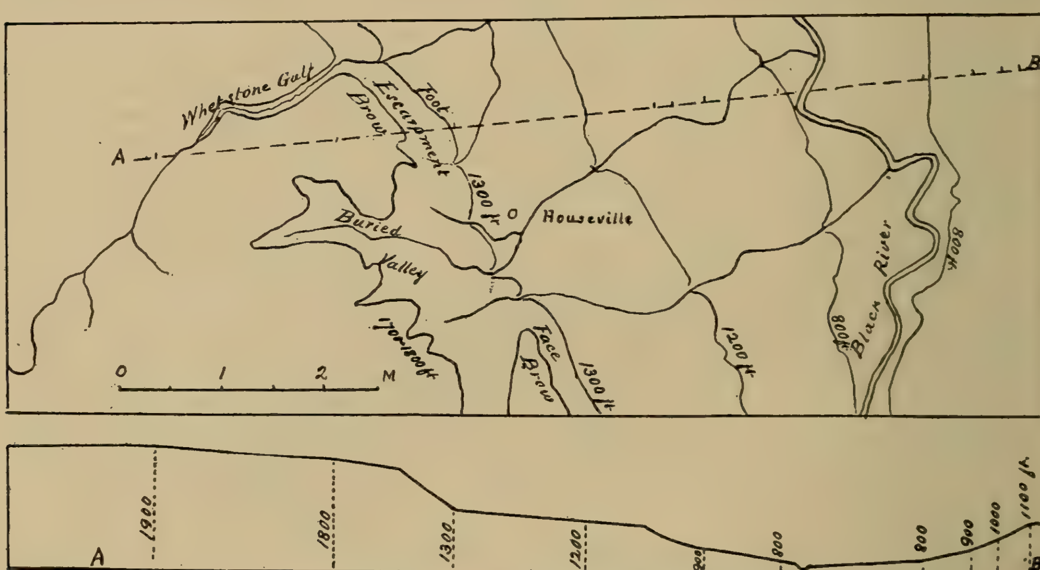

Figure 3.—*Map of the High Plateau dissected by Whetstone Gulf and its pre-Glacial Equivalent*

of the trunk valley, which had been deepened by the accession of the waters of the Chemung and its tributaries in the later pre-Glacial or early Glacial days. Where difficulties appear let us go into the field and hunt for the facts, for the region is full of interest and the details are not yet all brought to light.

Whetstone Gulf and its pre-Glacial Valley

Passing from western to northern New York, we find ourselves on the high plateau west of the Black River, which separates it from the Adirondack mass. The summit of the land tongue connecting this western

plateau with the main mass is situated at Boonville, at 1,135 feet above the sea. Northwest of this town is a well formed plain or plateau at an altitude of about 1,300 feet. To the east the steep slope faces the Black River Valley, some distance beyond which the country is underlaid by crystalline rocks at a much lower level. Immediately west of this plateau is an escarpment rising abruptly to the summit tableland, about 1,900 feet above the sea. The rocks are composed of shales of the Utica and Lorraine series, jointed and easily eroded. The summit is swampy, with a large area drained through Whetstone Gulf (see figure 3). Whetstone Gulf is a magnificent gorge 2 miles long, increasing to 1,000 feet in width and 500 feet in depth. Two miles to the south, at the Gulf Station, on a lumbering road at the border of the swamp, begins an insignificant gully. The little gully soon widens out into a valley with two or more tributaries and all, together, make a broad, deep embayment in the escarpment more than a mile wide, from which the drift filling has been partly removed (see figure 3). It opens to the lower plain near the hamlet of Houseville. This was the pre-Glacial drainage valley of the upper plateau, while that of the present day descends through the narrow gorge of Whetstone Gulf. Other similar indentations of the upper plateau also occur.

Prospect Falls on Side of pre-Glacial Gorge

Prospect Falls is situated on West Canada Creek, above Trenton Falls. Its striking feature is the broad cataract, descending some 25 feet over the northern wall of a buried canyon, which is only 200 to 300 feet wide, closed by drift above and below the falls. The outlet of this basin is through a narrow chasm in the southern rock wall, which is the beginning of the canyon of Trenton Falls. Until these falls had receded to this point the present basin was filled with drift with no cataract at Prospect; but as Trenton Falls cut through this rock wall of the buried channel the drift was removed and Prospect Falls commenced their descent. This was so recent that the cataract has hardly commenced to excavate a channel for itself in the newly exposed rock-bed.

Such hanging Valleys in northern New York no Evidence of glacial Erosion

Attention is called to these features, showing how that in this lately ice-covered region the glaciers did little erosive work, and that the occurrence of hanging valleys is no evidence of glacial excavations, even in

soft rocks; also that buried channels may be entirely obscured and yet occur where no suggestion of them appears at the surface, so that no argument can be based on their apparent absence beneath the drift of New York unless actually proved.

LOWER END OF THE GROS VENTRE SLIDE

In the foreground may be seen the broken mass of debris, with overturned aspens. The lower end of the lake is visible on the left, and beyond it the bare hills, which expose Cretaceous clays dipping gently to the north

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THE GROS VENTRE SLIDE, AN ACTIVE EARTH-FLOW[1]

BY ELIOT BLACKWELDER

(Presented by title before the Society December 28, 1911)

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INTRODUCTORY

Most settlers and others who have recently visited the mountains south of Yellowstone Park know "the Gros Ventre slide." Its wide reputation is due largely to the fact that for several years the landslide made communication between the upper and lower parts of the valley of the Gros Ventre River difficult and uncertain. Although the name which heads this paper is the one generally used in the vicinity, it is not quite satisfactory to the geologist, because it suggests the sudden plunge and immediate quiescence which attend landslides and avalanches in general. As the facts presented in these pages indicate, the term "earth-flow," or even "earth-glacier," would be more appropriate in this case.

The position of the slide may be found by consulting the southwest part of the Mount Leidy, Wyoming, topographic sheet, published by the United States Geological Survey. It occupies the valley of Lake Creek, one of the many small southern tributaries of the Gros Ventre River.

GEOLOGIC CONDITIONS AFFECTING THE SLIDE

In order to understand the phenomenon itself, it is necessary to know the geologic structure and topography of the locality. The Gros Ventre

[1] Manuscript received by the Secretary of the Society January 29, 1912.

For the historical data in this paper I am indebted to friends in Jackson Hole and vicinity, particularly to Mr. Robert E. Miller, Mr. S. N. Leek, and Mr. M. J. Robinson.
Published by permission of the Director of the U. S. Geological Survey.

River has excavated its valley roughly parallel to the strike of a thick series of rocks which dip gently northward. Along the south side of the valley, therefore, the strata dip at angles of about 10 to 20 degrees away

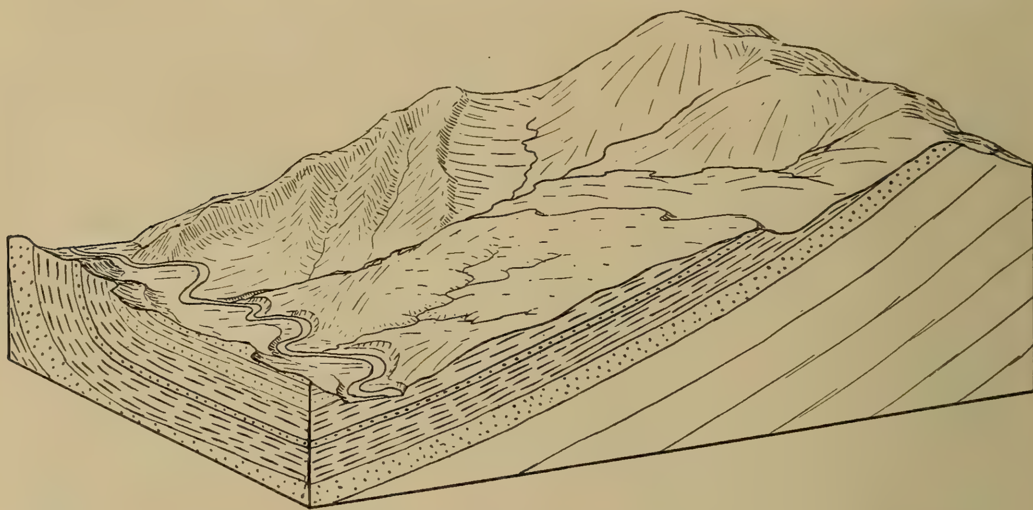

FIGURE 1.—*A diagrammatic Sketch of the Valley of Lake Creek as it is supposed to have been before landslide Action began*

from the Gros Ventre Mountains and toward the river. Locally this monocline is gently fluted with small cross-folds, and one of these forms the east side of the slide. In this locality the prevailing rocks are soft

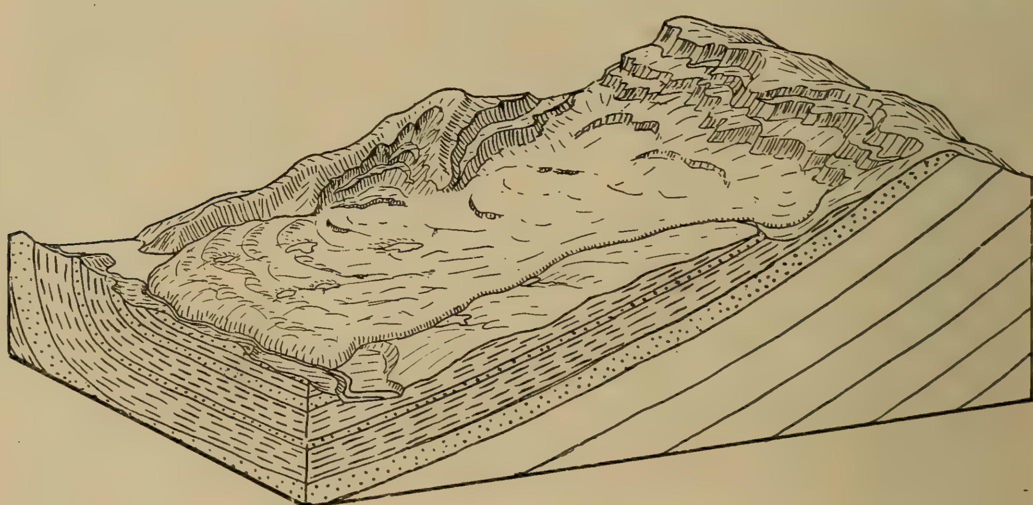

FIGURE 2.—*A diagrammatic Sketch of Lake Creek Valley in 1911*

These diagrams should not be regarded as faithful pictures; they merely serve to illustrate the general conditions

Upper Mesozoic shales with some beds of sandstone and a little limestone. They range in age from the Morrison and even Sundance (Jurassic) formations up to horizons equivalent to the Benton. Soft shale and clay predominate.

DETAIL OF THE SURFACE OF THE GROS VENTRE SLIDE

Showing the tearing of the sod and the uprooting of trees

ONE OF THE BULGING DOMES OF THE GROS VENTRE SLIDE WITH CREVASSES

These are characteristic of the lower part of the earth-flow

The edges of these argillaceous beds are upturned along the crest of a spur of the Gros Ventre Mountains, and in that situation readily become soaked with water from rains and from the melting of the snow in spring. At the lower edge of the slope the Gros Ventre River is actively widening and deepening its valley, and in so doing undermines the adjacent slopes from time to time. These conditions together favor landslide action of one kind or another. What actually happened in the case of the Gros Ventre slide may now be considered.

History of the Slide

Several years ago, before the disturbance began, the small valley now occupied by the slide was bottomed with a hummocky sheet of old landslide material which originated before any of the present settlers came to the valley. In that respect it resembled many other tributary valleys in the vicinity. According to residents of the district, the slide first came into action in May, 1908. So far as I am able to learn, no one actually saw it begin; but it is believed by some that the initial movement was fairly rapid if not indeed precipitate. When first observed, the disturbance was manifested only at the head of the gulch, where large masses of the slippery Morrison and Sundance (Jurassic) clays had slumped down along the steeper slopes, overturning trees and leaving a general wreck. Either quickly or slowly, the impulse from this upper mass was then communicated to the old landslide debris farther down the valley, and that in turn began to press forward, bulge, and crack. The novel thing about this case is that the movement of at least the lower part was very slow and yet continuous, like that of a glacier.

A man who passed along the valley of the Gros Ventre River by the main road in the fall of 1908 said that the jumbled mass of earth, rock, overturned trees, and undergrowth could be plainly seen half a mile or more above the road at that time, and I infer from his description that it presented a steep outer slope not unlike that of a glacial moraine. At that stage the only sign of disturbance at the road consisted of a long crevasse on the eastern edge of what is now the slide, but that sufficed to show that the lower mass was already beginning to move. Day by day this large crack became wider and developed subsidiary fractures, but the only sign of movement visible to the bystander was the constant falling of small particles of dirt from the walls of the crack.

Whether or not motion continued during the winter of 1908-1909 I have not learned; but in the spring of 1909 the material in the lower part of the valley slowly pushed forward and its surface bulged into low

irregular domes fretted with open crevasses, many of which were several feet wide. By its advance the glacier-like mass gradually obstructed the Gros Ventre River, which soon formed a lake more than a mile in length and several hundred yards in width. This still exists, but the rapid cutting down of the outlet has already (August, 1911) lowered the surface of the water about 10 feet.

So far as observed, the motion of the slide was not at any time rapid enough to be actually seen. The evidence of it, however, was plain enough. It was found impossible to keep the Forest Service telephone line in repair more than a few days, for the poles would slowly move down hill or be overturned and thus snap the wire. The wagon road soon became so hopelessly twisted and broken that it was almost impossible for wagons to follow it without capsizing, and it was no easy task to cross it even on a saddle horse. Attempts to repair the damage were almost futile, because in a few days the road would be rendered again impassable by folds of earth several yards in height or by gaping crevasses with vertical walls. In a short time the old road was completely destroyed, so that even traces of it are now hard to find. It thus became necessary for every one who attempted to cross the slide to pick out his own course, and not infrequently he was obliged to spend some hours with pick and shovel grading some of the worse places in order to render it possible to take a wagon over the slide at all.

According to members of the United States Forest Service, the slide did not move as one mass, but rather in sections; the disturbance began on the east side and manifested itself week by week at new places. Changes progressed most rapidly in the wet spring months and declined noticeably toward autumn. The slow but apparently incessant movement continued through the years 1908, 1909, and 1910, but in 1911 had practically ceased.

Present Characteristics of the Slide

As seen in 1911, the slide was a long glacier-like tongue of unassorted clay and coarser debris (see plate 31), much like till except for the absence of striated boulders, lining the bottom of a tributary gulch and spreading out at its lower end near the Gros Ventre River. At the head of the gulch the slopes are relatively steep and are seamed with parallel crevasses, along the lower sides of which the material has slumped down in waving belts. This oversteepening of the walls at the head of the valley suggests the cirque at the head of a mountain glacier. Like a glacier, also, the earth-flow thickens down the valley. Furthermore, in

CLOSER VIEW OF CREVASSES OF THE GROS VENTRE SLIDE WITH DISLOCATED SIDES

The wholly unstratified and till-like character of the material may be seen in the walls of the fissures

PORTION OF THE WEST EDGE OF THE GROS VENTRE EARTH-FLOW

The pond was formed by the obstruction of a small ravine

its topography the mass simulates a glacial moraine, for it is covered with orderless humps and hollows, scattered ponds and marshes. At the lower end the marginal slopes are relatively steep (plate 32) and rise several feet above the adjacent surface. By obstructing transverse ravines this steep edge has caused the production of small ponds. The abundant crevasses constitute a novel feature of the surface not found in moraines. These cracks will, of course, disappear in time, but now they are conspicuous on every hand.

Importance of Earth-flows

Older earth-flows or landslides issue from most of the gulches along the south slope of the Gros Ventre Valley and have been seen at other points in adjacent valleys. At first glance they are easily mistaken for glacial moraines, and where both occur together, as below Dorwin's ranch on the Gros Ventre, only the most painstaking and critical study will serve to discriminate the two types of deposits.

In this region earth-flowage of the kind described is one of the most important processes by which the adjacent mountains are wasting away. It must be ranked with stream erosion, ordinary slumping and glacial work, as an important means of getting material from the higher slopes down into the bottoms of the valleys, where streams can continue the deportation. That it is of great importance here and in a few other localities, but negligible in most other mountain regions, I ascribe to the fact that the operation of the process depends on somewhat unusual conditions: very weak unctuous materials exposed along rather steep slopes, and especially on slopes in which the strata dip downward with the surface. It is well known that in most Rocky Mountain and other uplifts the very weak strata, such as predominate in the Jurassic and Cretaceous formations, have generally been planed off to lowlands, leaving only the firm sandstones, limestones, and still harder beds to form the mountain slopes. This is believed to explain the general absence of earth-flows from such ranges as the Wind River Mountains, the Bighorn Mountains, and many others of the Rocky Mountain chain.

Classification

I find very few published descriptions of similar phenomena. In Science[2] Mr. Robert Anderson is reported as having described to the Geological Society of Washington certain earth-flows near San Fran-

[2] Science, n. s., vol. 25, 1907, p. 769.

cisco, in which unconsolidated material rendered semi-fluid by saturation with water had been caused to flow. The earthquake of 1906 seems to have started them.

Mr. Whitman Cross's photograph and description[3] of the "Slumgullion mud-flow," in southwestern Colorado, suggest some points of resemblance to the Gros Ventre slide. He thinks, however, that this flow must have been the result of one or two sudden slumps, but finds evidence of more recent readjustments in various parts of the mass.

The Gros Ventre slide differs from most well known landslides in that it had a period of slow and prolonged movement, whereas landslides are generally launched precipitately and end at once. In Howe's classification[4] of landslides it should be placed with the mud-flows, in which a mass of earthy matter saturated with water has flowed like a stiff liquid.

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[3] Cross and Howe: Landslides in the San Juan Mountains, Colorado. U. S. Geol. Survey, Professional Paper 67, 1909, p. 40.

[4] Ibid., p. 55.

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GEOLOGICAL RECONNAISSANCE IN NORTHEASTERN NICARAGUA[1]

BY OSCAR H. HERSHEY

(*Presented before the Society December 27, 1911*)

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INTRODUCTION

In the spring of 1910 the writer accompanied a party of mining engineers to the Pis-Pis mining district of Nicaragua. Landing at Cape Gracias á Dios, we ascended the Wanks, Waspuc, and Pis-Pis rivers, an estimated distance of 225 miles to the mines. Fifteen days were spent in the district, and then two of us descended the Tunkey, Banbana, and Prinzapulca rivers an estimated distance of 195 miles, to the mouth of the latter. Several days were also spent at Bluefields. Although the trip was too rapid to permit of detailed geological work except in the vicinity of a few mines, a series of observations were made that seem worthy of record.

Thomas Belt, who went to Nicaragua in 1868 to superintend the mining operations of the Chontales Gold Mining Company, describes[2] the

[1] Manuscript received by the Secretary of the Society December 6, 1911.

[2] The Naturalist in Nicaragua. Published in London in 1874.

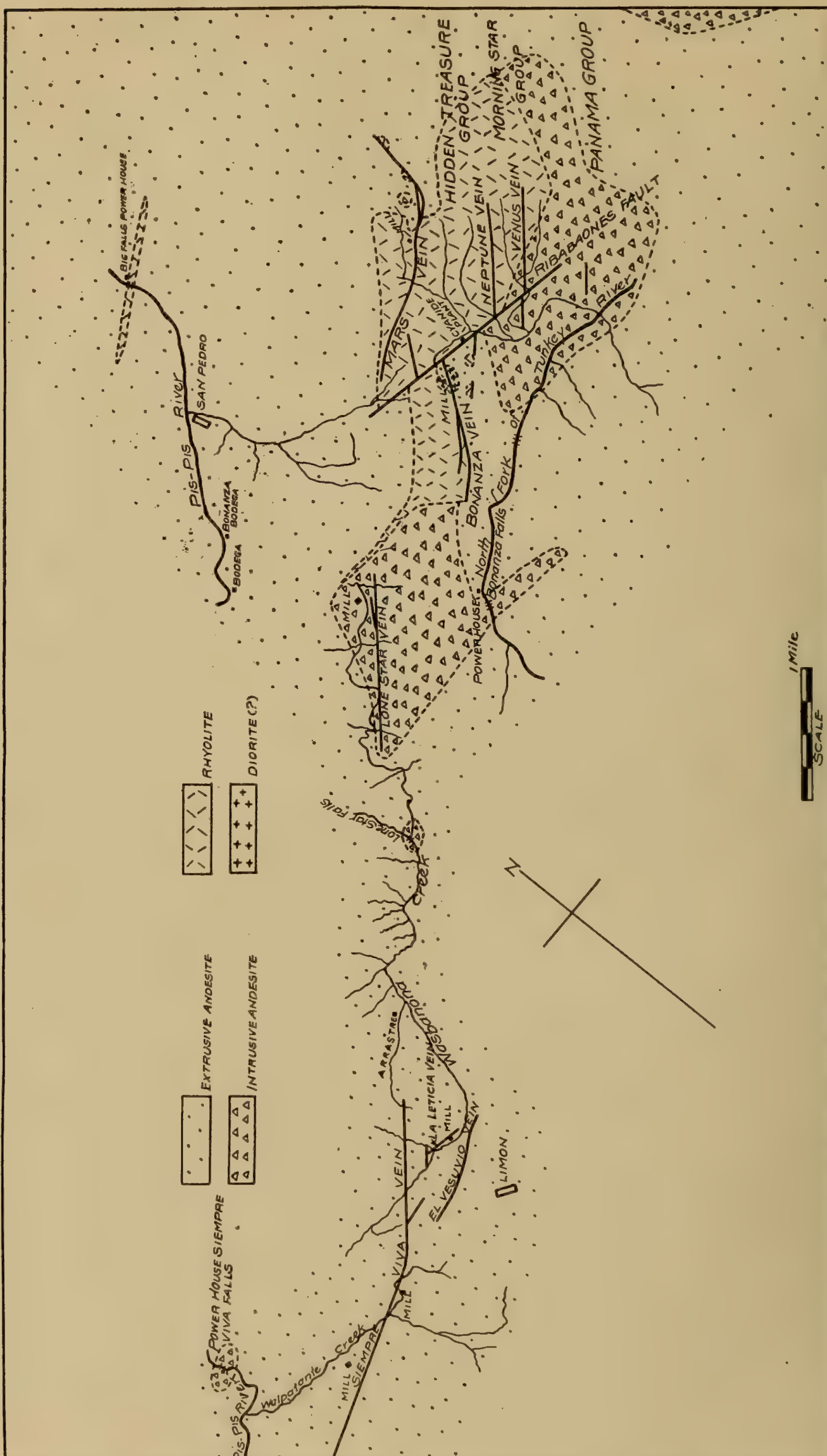

FIGURE 1.—*Geological Map of the Pis-Pis District, Nicaragua, by Oscar H. Hershey*

rocks in the silver-mining district of Depilto in Segovia as consisting of quartz and gneissoid beds which he likens to the fundamental gneiss of Canada. They are soon succeeded, in going down the valley of the Depilto, by overlying, highly inclined and contorted schists, "with many small veins of quartz running between the laminæ of the rock." The Depilto is one of the headwater tributaries of the Rio Wanks.

He describes the rocks in the Santo Domingo district, which lies about 115 miles south of the Pis-Pis district, as "dolerytes, with bands and protrusions of hard greenstones." The "doleryte" is decomposed to a depth of at least 200 feet. He says:

"This decomposition of the rocks near the surface prevails in many parts of tropical America, and is principally, if not always, confined to the forest regions. It has been ascribed, and probably with reason, to the percolation through the rocks of rain-water charged with a little acid from the decomposing vegetation."

Mr. Belt describes a ridge crossed by the road between San Rafael and Ocotal as

"very steep, and fully 1,200 feet high, composed entirely of boulder clay. This clay was of a brown color, and full of angular and subangular blocks of stone of all sizes up to 9 feet in diameter. . . . This boulder clay had extended all the way from San Rafael, and ranges of hills appeared to be composed entirely of it. The angular and subangular stones that it contained were an irregular mixture of different varieties of trap, conglomerate and schistose rocks. . . . The evidences of glacial action between Depilto and Ocotal were, with one exception, as clear as in any Welsh or Highland valley. There were the same rounded and smoothed rock surfaces, the same moraine-like accumulations of unstratified sand and gravel, the same transported boulders that could be traced to their parent rocks several miles distant. . . . The immense ridges of boulder clay between San Rafael and Yales, the long hog-backed hills near Tablason, the great transported boulders two leagues beyond Libertad on the Juigalpa road, and the scarcity of alluvial gold in the valleys of Santo Domingo could all be easily explained on the supposition that the ice of the Glacial period . . . covered all the higher ranges, and descended in great glaciers to at least as low as the line of country now standing at 2,000 feet above the sea."

J. Crawford, the government geologist of Nicaragua, divides[3] the country into five zones, the first or central zone made up of "Laurentian, Taconic, Cambrian, and Silurian rocks in the form of granites, gneisses, sandstones, porphyries, slates, quartzites, limestones, and hornblendes." The second division, a narrow belt on the east of the first, contains Carboniferous limestones, Permian magnesian limestones, red

[3] Abstract of a paper entitled "The Geology of Nicaragua." Proc. Amer. Asso. Adv. Sci., vol. xl, 1891, pp. 261-270.

sandstones and variegated shales, Laramie brown coal, and Cretaceous oolitic rocks and clays, gypsum, salt, and slightly metamorphosed sandstones. Glacial action is supposed to be indicated by low groups of hills or ridges of unsorted, generally unstratified deposits of clays and sands inclosing numerous stones and pebbles, some smooth and rounded, others angular. Mention is made of a few apparently glacially striated rocks. The Pis-Pis district lies near the eastern edge of this division, but the supposed glacial deposits do not extend into it.

The third division extends about 250 miles along the eastern coast and about 75 miles inland. No mention is made of the bedrock series. It is contended that this part of the coast has subsided until recently at a rate equal to that of the sedimentation over the delta of the rivers Escondido, Matagalpa, Tungla, Wanta, Segoria, and of several smaller streams. He thinks that during the supposed Glacial epoch in Nicaragua the land extended more than 1,500 miles farther east than at present, and that the eastern coast ceased to subside a few years ago and is now being slowly elevated, giving as evidences of the latter that the corals that grew nearly into the mouths of the rivers now are dead at the tops of their branches, due to the sediment-loaded river waters extending farther seaward than formerly; also that the atolls and barrier reefs off the coast have the peaks of their coral formations exposed and dead above all ordinary tides and storm waves. He also describes two river systems in the country immediately west of the delta region, one including the dry beds of ancient rivers and the other the present river channels. The former are from 100 to 500 or more yards wide and traceable for many miles.

In 1893 Crawford described[4] "granite outbursts" exposed on the tops of oval-shaped cerros, and also occurring in two parallel lines of spurs and ridges that extend northeastwardly for about 90 miles from the Barbar Mountains to near the confluence of the Rios Wasspuc and Wanque (Wanks). He also describes so-called moutonnéd ridges as evidence of glaciation over several thousand square miles. They extend in a series of parallel oblong ridges 60 miles northeastward from near the base of the tall Barbar and Peña Blanca Mountains, the altitude of which is over 7,000 feet above the sea. One of the "moraines" extends farther northward, is 90 miles long, and terminates at a dike on the sides of which are auriferous gravels, in which the Rio Wanque has cut its channel at San Ramon. The "moutonnéd ridge" country has a width of 25 miles from east to west and the ridges rise 70 to 400 feet above

[4] Recent discoveries in northeastern Nicaragua, etcetera. Science, vol. xxii, 1893, pp. 269-272.

the creeks. They are composed generally of unstratified clays, sands, gravels, and boulders. The latter, 10 pounds to several tons in weight, are usually angular and subangular and composed generally of auriferous quartz, granites, syenites, and other hornblendic and feldspathic rocks. The ridges have been greatly eroded and the boulders exposed. To my keen regret, my travels did not quite extend to this intensely interesting "glaciated" region.

Courtenay De Kalb visited the Siempre Viva mine in the Pis-Pis district and says:[5]

> "The geology of the region is very simple. Along the eastern flanks of the mountains occur carboniferous limestones, upon which lie unconformably red sandstones and variegated shales evidently belonging to the Permian period. Basaltic dykes have obtruded through these rocks at many places, and higher up all traces of the Permian formations are lost sight of, the mountain masses being composed entirely of rocks of the dioritic group, largely porphyritic, and of metamorphosed shales. It is along the lines of contact between diorites and shales that the veins are found."

C. Willard Hayes, as the result of a study[6] of the "Nicaraguan depression," thinks that in early Tertiary times the Atlantic and Pacific were united across Nicaragua; that the country was elevated in mid-Tertiary times, and this was followed by a long period of erosion which developed a broad peneplain, above which are residual hills, most abundant at the axis of the isthmus, where the continental divide was formerly located, but merging northward with the mountains of northern Nicaragua; that another elevation (of 200 or 300 feet) resulted in the erosion of valleys beneath the peneplain, and that the latest episode has been a depression of 100 or 200 feet that has drowned the lower portions of the river valleys, and the drowned portion has been largely silted up.

W. A. Connelly has described[7] the country rock of the Pis-Pis district as "a flow or succession of flows of andesite, much fractured and highly altered near the surface," and T. Lane Carter says[8] that it is generally porphyry.

Quaternary Deposits

DETAILED DESCRIPTIONS

The Wanks River enters the Caribbean Sea at the end of the prominent headland known as Cape Gracias á Dios. The headland consists

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[5] The new gold fields of the Mosquito coast of Nicaragua. Eng. and Min. Jour., vol. lvii, pp. 294-295.

[6] Physiography of Nicaragua Canal route. Nat. Geog. Mag., vol. x, 1899, pp. 233-246.

[7] Pis-Pis district, Nicaragua. Min. and Sci. Press, vol. 100, No. 10, March 5, 1910, pp. 350-351.

[8] Mining in Nicaragua. Bull. Amer. Inst. Min. Eng., No. 48, December, 1910, pp. 965-1001.

entirely of the alluvium of the river and of beach deposits. The river has two mouths, and all the land bordering on them is very low, probably only a foot or 18 inches above ordinary high-tide level. Very little of it is marshy, although there are a few small lagoons back of the beach. No evidence was seen here of the recent elevation of the coast mentioned by Crawford.

In ascending the Wanks River, on May 11, 1910, when it was probably at its lowest stage, the following observations were made: As far up as the Indian village of Living Creek, said to be 56 miles from the mouth of the river, but probably about 45 miles, the stream is from 100 to 150 yards wide and apparently rather deep. It winds about in great curves in a broad delta plain. The banks are steep and very gradually increase in height. At the Colimer ranch, said to be 12 miles from the mouth, the bank is 6 feet high, of which the lower 4 feet consist of light-brown sand, the next 8 inches of black and dark reddish material like a buried soil, and the upper 16 inches of brown sandy alluvium. Shells of species now living in the river are abundant in the upper stratum, less so in the dark layer. From the edge of the bank on the north side of the river level savannas extend back several miles.

In the vicinity of Living Creek the banks were 10 to 12 feet high. In ordinary years the river apparently does not reach the top, but occasionally it overtops them a few inches and floods the alluvial plain for a short time. The alluvium as seen from a boat seems largely clay below, passing to silt above. It is in bands of reddish brown, dark gray, and light brown. Bars of light-colored sand appear on the inner sides of curves. No gravel was seen below the village, but bars of fine gravel appear a short distance above it. The river continued to be about 100 yards wide and to have steep 10-foot banks of banded alluvium, but there is said to be higher ground at a distance of several miles back from it. We had apparently passed out of the Modern delta proper into a broad, alluvium-floored valley, in which the river winds as in the delta. The country bordering the valley is said to consist of low ridges and may be the dissected remnant of some older delta deposit. The tropical vegetation on the banks and the fact that I traveled in a small boat prevented me from seeing any part of these ridges for many miles after we were said to have entered the valley between them.

At Sawa the banks are 18 to 20 feet high and no higher land can be seen from the village. An extensive bar between the stream and the bank consists of fine gravel, largely white quartz. The alluvium in the banks is partly sand, partly the claylike banded material. Fine gravel appears in places at the foot of the sandy bank.

Thence upstream for many miles the country maintains the same character. The river trench averages probably 150 yards wide and 20 feet deep. One-third of it is occupied by the fine gravel bars and the remainder by the stream, which is relatively shallow and flows with a good current. The banks of variegated clays or clayey silts alternate with equally high and steep banks, consisting of fine gravel and rusty colored sand at the base and stratified brown sand above. The variegated clays may be the back-swamp deposits and the sand banks the material filling old channels or built up on the inner sides of the curves, so that both classes, though rather strongly contrasted in appearance, may represent the same general period of alluvial deposition.

At the village of Ryapura there was a bar of quartz gravel 4 feet high and 20 yards wide. The maximum diameter of the pebbles was 2 inches, though few exceeded 1 inch. Some chalcedony and brown chert was noted. The gravel was rusty colored within 18 inches of the river level, indicating the presence of considerable of an iron salt in the water at the low stages. The bank behind the bar was 18 feet high above the stream; no high ground was in sight from the top, but the tropical vegetation prevented an extended view.

Above a point probably about 100 miles from the mouth the river trench is about 200 yards wide and the banks 15 to 18 feet above the low-water stage of the stream. The gravel in the bars has become coarser and in places has been cemented by limonite into a soft conglomerate. Gravel rises high in the banks and is overlain by brown sand. The variegated silts are scarcely represented. Small creeks enter the river from very narrow V-shaped trenches.

At one place the river trench passes out of the old sand-filled channel into the variegated silts, where it is noticeably narrowed and the stream deep. Near the water level the bank has a nearly black layer that is probably due to the accumulation of vegetable matter in the old back swamp. Higher there are several dark gray layers of similar origin. Dark bluish gray and greenish layers and lenses in the fine gravel and sand layers of the old channels are common near the low-water level and are probably due to local deoxidation of the reddish brown material. The dark layers in the variegated silts are more regular and I think were originally dark in color. After several miles in which the banks are largely gravel, brown sand appears again and is finally succeeded by the variegated silts a short distance below Saclin.

At Saclin, which is said to be 115 miles from the mouth of the river, we encountered the first ground higher than the Modern alluvial plain. The village is situated on a bluff which rises 35 feet above the low-

water stage of the river. The face of the bluff presents fine exposures of the material. At the base is a dull olive gray, claylike material which may be a decomposed volcanic tuff. Portions near the top are stained to an intensely red color. The surface of the claylike member is undulating. It is overlain by a bed of slightly cemented gravel, which extends to the top of the bank and may be 25 feet thick in places. The pebbles are well water-worn and average between one-half and 1 inch in diameter (rapid estimate), though some are 5 inches in length. Most of them consist of hard white quartz, and not sufficient time was available to determine the other rock species represented. The gravel is white in color, with a light red stain in the cementing material. The entire deposit is roughly stratified, but I could not determine whether it is marine or fluviatile in character. No shells were seen in it. Springs of water come out at the base of the gravel, as the underlying formation is relatively impervious to water.

This bluff is the northward end of the so-called "Pine Ridge," which is said to extend to the Wawa River and to be represented both north of the Wanks River and south of the Wawa River. It is described as a broad rolling upland, in places a succession of small hills, with many small creeks in the ravines. At Saclin the surface is distinctly but smoothly rolling, suggesting that it is a remnant of an old dissected plain, either a coastal plain or an old delta plain. The characteristic feature of it is the growth of pine on it. It is said that away from the vicinity of the streams there is no underbrush, but a great open pine forest. The tree resembles the southern yellow pine of Louisiana. I attribute its presence in a country which elsewhere abounds in the tropical type of vegetation to the gravelly composition of the subsoil, which makes the "ridge" a region of relative aridity unfavorable to the tropical vegetation. The "ridge" country is said to have a black soil 18 inches deep and below that a great bed of white gravel.

The 35-foot bluff extends to at least a mile above Saclin. Much of the gravel member is white in color and stands with a vertical face. The claylike member under it resists erosion and, seen from a short distance, resembles hard rock. Then the river swings away from the bluff out into the broad floodplain and is bordered by gravel bars or steep banks of gravel and brown sand about 15 feet high. The river again touches the 35-foot bluff on the south side about 10 miles above Saclin. Bright colors appear, but the bank is largely covered by vegetation. From the top a plain is said to extend to and connect with the "Pine Ridge." Several miles farther upstream the south bank of the river exposes a section similar to that at Saclin, except that the lowest stratum

is lighter in color and from a boat appears decidedly like a rather coarse tuff of massive structure.

At Kissalya the tufflike stratum at the base of the 35-foot bluff rises 6 to 8 feet above the low-water stage of the river. The bulk of the material over it is gravel, in part white, in part stained bright red. As seen from a boat, the very bright red clays over the dull colored tufflike stratum seem irregularly interstratified with the lower half of the gravel formation.

At Mocoring rapids, said to be about 140 miles from the mouth of the river, there is the first exposure of hard bedrock seen in ascending the river. The channel at low water is studded with black rocks that may be basalt. Similar rock appears in the river bed several miles farther upstream. The banks are Modern alluvium. Then the river swings away from the vicinity of the south bluff, and at about 7 or 8 miles from Kissalya it evidently reaches the north bluff. A bank about 60 or 70 feet high seems to consist largely of the light gray, massive tufflike material. A little farther upstream a bluff may be seen on the north side of the river beyond a narrow strip of Modern alluvium; it is covered by a fine forest of tall straight pines. Beyond on the north is an extensive pine-clad rolling upland, the highest portions of which are probably several hundred feet in elevation above the river.

At Soulala (Red Bank) the pine comes down on to a lower terrace, whose riverward escarpment is about 30 feet high and consists of stratified gravel and variegated but dull clayey silts, judging from their appearance from a boat. They resemble the variegated silts seen farther down the river and may represent an early stage of the river's floodplain. The banks of gravel and brown sand that represent the Modern alluvium are about 15 to 20 feet high. Hence we have here in sight at one time three terranes as follows:

1. A dissected coastal (?) plain.
2. An old river floodplain partly filling a broad shallow valley trenched across the coastal (?) plain.
3. The Modern river floodplain partly filling a broad shallow channel trenched in the older floodplain deposit.

Next the river takes a long reach toward the south bluff and presently exposes black basalt-like rock under the Modern alluvium and in the channel. It swings back against the pine-clad north bluff, and thence to San Domingo the banks of Modern alluvium alternate with high banks in rapid succession. At the San Domingo ranch the river has cut a channel 200 to 400 feet wide through a broad undulating ridge of andesite lava with flow structure. It has a black coating and resembles the

rocks seen farther downstream, so that the latter may be andesite instead of basalt.

Andesite is present in the banks for several miles upstream, but the rock which produces the Lalacapisa rapids, where examined in the channel, is a black conglomerate with many quartz pebbles. Above the rapids for about a mile the banks show only the gravel and brown sand of the Modern alluvium.

Then the stream exposes on the north side a fine section of the variegated silts and fine quartz gravel of the older alluvium. From the top of the 30-foot bank a pine-clad, much-logged plain extends back from the river. At the next good exposure of the Modern alluvium it seems to rest on a much harder formation of dark gray conglomerate. I surmise that the dark-colored conglomerates seen at many places along the river, as at the Lalacapisa rapids, are merely portions of the Modern gravel cemented by limonite.

Dark rocks exposed on the south side of the channel at Wirapani are probably andesite with flow structure. More of it is exposed upstream, but it nowhere rises higher than the floodplain, so far as can be seen from the river. Black rocks exposed higher up resemble basalt, even to an imperfect columnar structure, but we did not land on them. It is probably safe to say that this country has a formation of lava sheets (and probably some tuff beds) prevailingly andesitic, though more basic and more acid rocks may be present in the series.

At a bend, probably about 10 miles below the mouth of the Waspuc River, we got our first view of the mountains of the interior. There seemed to be a peak and sharp ridge rising abruptly from the low plain, but the view could not be depended on in this respect.

In a bar of coarse gravel several miles farther upstream more than 50 per cent of the pebbles and cobbles were of white quartz. Many varieties of andesite were the most abundant in the remainder. There were also porphyries, diabase, diorite, red and brown chertlike rocks, probably a little gabbro and basalt, some chalcedony, a hard quartz conglomerate, an andesite tuff, a finely foliated gneiss, a black slate, jasper, and an amygdaloid, but no granite, limestone, sandstone, nor fossils.

Black rocks, presumably andesite, are scattered at intervals nearly to Suhie, where the "Pine Ridge" country appears again. Here the bank exposes white gravel (false-bedded near the river level) sufficiently indurated to stand in a vertical bluff and probably the same formation as at Saclin. Then the river swings out into the Modern floodplain. The deposit has changed very little in many miles. The gravel is moderately coarse, of a light yellowish color, and usually rises one-third or one-half

of the height of the bank. Above it is brown sand. The banks impress one traveling in a boat as being 15 to 20 feet high, but may be 25 or even 30 feet high in places. Of course, most of the year the river is 5 to 10 feet higher.

At Swabin the north bluff, at the edge of the pine country, is a reddish bank of fine gravel and silt, suggesting the variegated silt formation. Its surface is even, but some of the pine country in sight may be a little higher. At the upper end of the bluff dull greenish and dark carbonaceous layers are present. Thence to the mouth of the Waspuc River the banks, 30 feet high, are of Modern alluvium, with an occasional exposure of black rock, presumably andesite. That on the south side of the Wanks River, half a mile below the Waspuc, is a dark brown vesicular lava of rather coarse crystalline texture. Some of it is decidedly basic in appearance and some abounds in feldspar phenocrysts. It impressed me as being about on the border line between a basalt and an andesite, but the microscope would probably prove it to be the latter. The rock exposed opposite the mouth of the Waspuc is a very coarse volcanic agglomerate, made up of quite a variety of andesites. Near the water level it is hard and black on the surface, but higher in the bank it is very much decomposed. The bank is nearly 50 feet high, flat on top, and said to become stony at a short distance from the river and in a mile to pass into the pine country.

The trading post of Waspuc Mouth is situated on the floodplain, which rises 30 feet above the low-water stage of the river, but has been covered during an abnormal flood by 6 or 8 feet depth of water. No higher ground is in sight on the south on account of the tall trees. The distance to the mouth of the Wanks River is said to be 194 miles, but was estimated by us at 145 miles.

In ascending the Waspuc and Pis-Pis rivers to the Big Falls, an estimated distance of 80 miles, bedrock was frequently seen and will be treated more fully in a later section. The Quaternary deposits consist exclusively of the Modern alluvium and the soil. The Waspuc River at first flows in a channel 100 to 200 feet wide, with 30-foot banks of dark reddish brown sandy silt, with only a few small gravel bars at low levels. Above the Yahook Falls the banks are only 10 feet high and for a long distance the river is relatively wide and sluggish. Then narrow rocky gorges alternate with wide, alluvium-floored sections of the valley. In one bar the gravel consisted chiefly of andesite of finer grain than most of that seen down the river. With it were various kinds of fine-grained igneous rocks, including a hard greenish rock that may be an altered andesite. The silica pebbles are generally chalcedonic. Much of the

gravel suggests an older volcanic series than that seen down the river. A few pieces were doubtfully identified as diorite. No sedimentary rocks were certainly represented, certain shaly flinty rocks having been probably altered volcanic material. There were no typical rhyolites present, though some of the pebbles appeared rather more acid than an andesite.

The Pis-Pis River for about 10 miles upstream to the Yapooketan Falls is in a trench usually 50 to 75 feet wide, which evidently winds about in a floodplain. The banks are chiefly the brown sandy silt of the Modern alluvium. At the falls the river probably cuts through a small range of hills, as the banks are much higher and more uneven than farther downstream. The river may fall 20 feet within 300 yards. To the mouth of the Guavel River the Pis-Pis is about 50 feet wide and flows in a crooked trench largely lined with alluvium. Above the Guavel it is reduced to a width of about 30 or 40 feet and has the usual alluvial banks. The stream is a succession of long quiet reaches and short rapids. The latter are so numerous that one is surprised to learn that the altitude, as determined by aneroid readings, is but 472 feet at the Big Falls bodega, the gateway to the Pis-Pis mining district.

The topography of the Pis-Pis district is that of an ancient and deeply eroded volcanic region. The more resistant rocks form the hills. The principal valleys are generally eroded in andesite lavas and tuffs, but where traversed by hard ribs of intrusive rock the streams cascade over them in falls from 10 to 230 feet high. The district ranges in altitude from about 600 to about 1,700 feet above sealevel, but much higher mountains occur at a short distance on the northeast and northwest sides. It is a curious fact that although it is on the divide between the Wanks and Prinzapulca river systems, much more mountainous country occurs in all directions from it except a small section on the north and another on the southwest. There are several very low passes on the divide.

A view toward the south and west from near the Mars mine shows an unsystematic grouping of many uneven-crested ridges covered by the almost unbroken tropical forest. Some of them probably rise to 2,000 feet above sealevel. Their crests appear to be narrow and their slopes generally steep. Between them are rather broad valleys, the floors of which, however, are not to any great extent even. They are crossed by low ridges of hard rocks, over which the streams cascade. Looking off toward the north, there seem to be rather broad-floored valleys along the main streams, as the Guavel, Pis-Pis, and Waspuc rivers, and the ridges are low for perhaps 20 miles, but beyond that there are several prominent mountain ranges apparently trending easterly.

A magnificent view may be had from the top of the Lone Star Hill. Toward the northeast it is limited at the distance of 5 to 7 miles by the "Wava Peaks," a high, very uneven-crested ridge, whose principal peak may attain an altitude of 3,000 feet. To the left and much farther distant can be seen several long, uneven-crested mountain ranges. Directly north is a broad, flat-floored valley that may extend from the Big Falls on the Pis-Pis River to the Wanks River. It seems bordered on the north by low mountain ranges in Honduras. A little farther west of north there is a group of high mountain ridges. Ten miles due west (magnetic) would take one into the heart of a group of mountains, whose summits probably average 2,000 feet above sealevel, rising westward into a higher range. After a group of lower mountains there is an isolated high peak bearing about south 55 degrees west (magnetic) from Lone Star Hill. Another high peak may be seen to the left. These are the Cerro Salai (reputed altitude, 6,500 feet) and the Cerro Pia (reputed altitude, 6,000 feet). In the foreground is a country of low mountains. Over all the mountains, no matter how high and rugged, is the dense tropical forest, except possibly at the summits of the two high peaks. No volcanic cones are in sight. It is a rather old erosion topography with some unusual features due to the great forest and the humid climate. The land has been reduced far below the original volcanic surface, and if a peneplain was developed subsequent to the cessation of volcanic activity it has been completely destroyed. In short, all the hills are residuals, but the valleys are not baseleveled except locally by hard ribs of rock. The topography indicates the relative resistance to decomposition and erosion of the rocks to a great degree.

In descending the Tunkey River 20 miles from Barbones, we found the same alternation of alluvium-floored sections of valley and relatively narrow rocky gorges. The village of Tunkey is situated on the high bank in the angle between the Tunkey and Banbana rivers. The latter stream at about 5 miles west seems to break through a high mountain range apparently trending north. From the village it flows southeastwardly in a moderately broad, even-floored valley, near which there are several hill peaks. To the south the country is evidently rolling, without any prominent peaks, but northward, toward the Oconguas country, the ridges rise higher in the distance until they culminate in a high and abrupt range.

The Banbana River in the first 8 or 10 miles below Tunkey evidently winds about in a rather narrow valley. The banks are generally 30 to 35 feet high, and consist in part of clay produced by the decomposition of the bedrock and in part of the brown sand of the Modern alluvium.

Rocks low in the banks, seen occasionally from the boat, appeared igneous. Some limonite-cemented Modern gravel occurs under the brown sand. At a gravel bar near the landing of the Santa Rita mine it was difficult to distinguish any rock species except a few andesite pebbles. The gravel is largely light-colored material, probably produced by the alteration of sedimentary rocks. There may be some chert from a limestone area, some quartzite and some rock that resembles a decomposed granite, but there is nothing definite about them. I suspect that the region is largely one of sedimentary rocks abounding in intrusives.

Thence the river is generally winding about in a broad floodplain, though it occasionally touches the side of the valley and exposes rock and low hills. The Wasaki Falls is caused by an outcrop of apparently igneous rock. The same is true of the Walpitara Falls, though none was secured for close examination. Below the falls the stream resumes its interminable winding in the floodplain. Presently we passed a low bank of dark red stratified material tilted at an angle of about 70 degrees. The coarser layers were speckled and had the appearance of an andesite tuff. In a few hours evidences of bedrock had disappeared and we had entered a region of deep water, winding constantly between 20 to 25 foot banks of brown sand and silt. Next morning we passed a series of rapids caused by reefs of rock of a nearly white to light gray color. Its general appearance suggested a horizontally stratified fine-grained sandstone. There were no hills near the river. The alluvial banks gradually became lower, and gravel and even sand beds disappeared from them, being replaced by stratified brown silt and massive, light-colored mottled clay. A number of small rapids passed early next morning I suspect were due to Modern alluvium locally cemented by limonite. We had entered the delta country and could see no hills from the bank. Near the mouth the river is deep and sluggish, 100 to 125 feet wide; the banks, of brown silt, are about 8 feet high, and apparently back of the fringe of bamboos, scattered trees and bushes on the river bank there is an open country, either savanna or swamp.

The 30 miles of the Prinzapulca River traversed is 100 to 150 yards wide and winds about somewhat in the apparently swampy delta. The town of Prinzapulca is situated on the south bank of the river between the beach and the swamps. The Prinzapulca has not built a prominent headland into the sea as has the Wanks. The beach deposits average several hundred yards wide and in general rise only a few feet above ordinary high-tide level. They consist of brown sand with patches rich in heavy black sand, presumably magnetite. There are a few scattered small pebbles, and fine gravel is said to appear on the beach 6 miles south.

Behind the beach is a broad country of swamps. No hills are in sight. Within several miles of the mouth, the Prinzapulca River has scarcely any banks, properly so called, as a rise of 1 or 2 feet would carry the water over into the swamps. In going inland the first high land reached is said to be the "Pine Ridge," lying between the Prinzapulca and Grand rivers, reached about 60 miles up the former and 20 miles up the latter. Another section of "Pine Ridge" country is said to lie between the Banbana and Wava rivers. At Bluefields the low hill country of igneous rocks (much of which resembles an altered rhyolite, some andesite tuff much altered, and other dark-colored rock may be basalt) comes out to the very edge of the Caribbean Sea, but the great delta country appears north of the bluff.

MODERN ALLUVIUM

This includes the deposits in the broad delta region along the coast and the younger floodplain deposits in the valleys extending back into the mountain region. It is predominantly a brown sand, varying to silts and clays near the coast and gravels in the mountains. The beach deposits and the deep red soil of the hilly country are referable to the same epoch, though the soil is the result of processes that have been continuous throughout the Quaternary era at least.

SOULALA FORMATION

In the valley of the Wanks River there is evidently an older alluvium, characterized by variegated silts and clays, with a little associated gravel and sand. At Soulala it is distinctly higher than the Modern alluvium, but farther down the river can not be distinguished as a topographically separate floodplain. It is probably of about the age of the Wisconsin drift sheet in the United States. Black carbonaceous layers may suggest a cooler climate during its formation, but there is nothing else about it to indicate extensive glaciation in the upper portion of the river's basin during its deposition. However, the supposed glaciation may have corresponded in age with an epoch of erosion and not deposition in the lower portion of the basin.

SACLIN FORMATION

Pine evidently grows on several formations, but there can be little question that the so-called Pine Ridge country owes its distinctive characters largely to a deposit of fine white gravel that is distributed north and south across the country as a fringe to the mountainous interior,

sending long arms far into the delta country. It is typically developed in the bluff at Saclin. The character of its distribution points toward a marine origin. The pebbles are predominantly white quartz, probably largely derived from the gneissic and other old formations described by Belt and Crawford from the headwaters of the Wanks River, although they adjoin a region predominantly igneous. I attribute this to the action of the sea in wearing out the softer igneous rocks. The quartz gravel of the Lower Wanks probably comes largely from erosion of the Saclin formation.

In short, the "Pine Ridge" country is probably an old dissected coastal plain. The old river channels mentioned by Crawford probably emerge from the mountains at the same level. It may also be fairly safe to correlate this coastal plain with the peneplain discriminated by Hayes in the "Nicaraguan depression." In age the Saclin formation is probably rather early Quaternary.

Tertiary Rocks

IN GENERAL

Being in the great Atlantic forest, with an average annual precipitation of about 138 inches, a minimum temperature at the Bonanza mine of 52 degrees Fahrenheit and a common daily range of 60 degrees Fahrenheit to 90 degrees Fahrenheit or 96 degrees Fahrenheit and a dense vegetation, the rocks of the Pis-Pis district are near the surface most thoroughly decomposed and the areal geology extremely difficult to study except along the larger creeks, in the mine excavations, and at wide intervals in the trails. The zone of oxidation probably averages 100 feet in depth on the hills. Where the soil is stony, the rock fragments are almost exclusively the debris from quartz veins. Accurate detailed mapping is impossible except in the vicinity of the best developed mines. Furthermore, it was difficult to secure fresh material for microscopic study. A set of thin-sections was submitted to Dr. A. C. Lawson, who has kindly furnished me the descriptive notes printed herewith in small type. They were made by one of the students at the University of California, but reviewed and amended by Doctor Lawson, who is responsible for the names that I am going to apply to the rocks.

ANDESITE

The larger part of the district is occupied by an extrusive series of andesitic composition. Its structure is generally obscure, but frag-

mentals were distinctly seen at three places and it is probable that they make up a large part of the series. The fresh rock is generally of a dark greenish gray color and fairly hard, but at most of the outcrops the andesite lava has a dark red to purple color because of partial decomposition. Weathering converts some of the rock to a soft, deep-red mass with white spots due to the kaolinized feldspars. This is the form in which it is generally seen in the walls of the veins. Near the surface it becomes a mass of stiff red clay.

A specimen from the trail on the north of the Mars vein has been identified by Lawson as andesite and described as follows:

I. In thin-section the rock shows a medium-grained structure, with feldspar crystals of porphyritic habit, in a fine-grained and glassy ground-mass. The rock shows signs of severe alteration, as the feldspars are full of calcite and kaolin, and the ground-mass is full of calcite, chlorite, and epidote. The rock is essentially composed of plagioclase feldspars of two generations; these make up the bulk of the section. The original ferro-magnesian minerals are entirely lacking, having been replaced by the epidote, calcite, and chlorite, which occur, especially the chlorite in porphyritic-shaped masses. Magnetite occurs throughout the section, but due to alteration; most of it has been altered to limonite.

Along the Mars power-line, one-half of a mile northwest of the Mars mine, there are hard residual boulders that have weathered out of the reddish-stained andesite, and a specimen has been described, under the term "augite andesite," as follows:

VII. The rock is dark colored, medium-grained, with a decidedly porphyritic structure, the feldspars occurring as large phenocrysts in a dark glassy ground-mass. Fine grains of magnetite give the glass the dark color. The alignment of the phenocrysts gives evidence of a flow structure. Augite occurs as well developed phenocrysts. There is a slight attempt at a diallage cleavage in cross-sections of the augite prisms. The augite occurs in crystals up to one-eighth of an inch long. A large amount of the augite has undergone alteration, and has been replaced by chlorite, epidote, and magnetite. The augite has been formed prior to the feldspars. Magnetite occurs abundantly as large crystals of primary origin, and as small secondary magnetite, as an alteration product of the augite. The feldspars are the most abundant mineral present. They are perfectly fresh and unaltered. Their extinction angle shows them to be labradorite. They occur as large phenocrysts one-quarter of an inch long and as small lath-shaped crystals in the ground-mass.

This rock I believe to be fairly typical of the majority of andesite outcrops seen in ascending the Wanks, Waspuc, and Pis-Pis rivers, and it evidently has a wide distribution in northeastern Nicaragua, particularly in the valleys and under the old coastal plain. There seems to be a large, scarcely interrupted area of it along the Pis-Pis River above the

Big Falls, including the vicinity of San Pedro. It forms part of the hanging wall of the Bonanza vein toward the northeast and the foot-wall toward the southwest. The northeastern part of the Mars vein is largely in it. It occurs extensively as wall rock to the veins in the southwestern portion of the district, including the Siempre Viva, El Vesuvio, La Leticia, La Constancia, and Santo Domingo veins. It is the rock that De Kalb called diorite, Connelly andesite, and Carter porphyry. A specimen representing the foot-wall rock at the Siempre Viva mine, but secured from a boulder in the dirt back of the mill, was described as follows:

III. In thin-section the rock is of a medium-grained porphyritic structure with a glassy ground-mass. The original ferro-magnesian mineral is absent, being replaced by epidote and calcite. Unlike section No. 1, there is very little chlorite, the decomposition being more in the nature of the separation of magnetite. This occurs in very fine grains, shot through the glassy ground-mass, giving it a black appearance. The rock itself is extremely magnetic. The feldspars are in amount the most important mineral. These were determined as labradorite. They occur as large phenocrysts and as small lath-shaped crystals imbedded in the glassy ground-mass. These small feldspars show a tendency toward orientation in a general direction, indicating flow structure.

The extrusive andesites are apparently intruded by harder, heavier, darker crystallines which resist decomposition better and are most likely to outcrop and produce residual boulders. From their tendency to appear near the surface as dark green rocks, I used for them the field designation "greenstone." They decompose near the surface to a stiff bright red clay, but the decomposition does not extend nearly as deep as in the other rocks. At the Panama mine some of the material seems to be in small dikes cutting an andesite agglomerate.

On the hanging-wall side of the Bonanza vein there is an oval area of "greenstone" 500 feet long and 285 feet in maximum width. It does not quite touch the vein and on that side contacts with the ordinary andesite. On the west it is bordered by an acid intrusive rock. A hard kernel from the Bonanza mill grade was identified by Lawson as holocrystalline andesite and described as follows:

II. The rock has a greenish color, is fine-grained and holo-crystalline. In thin-section it seems to be made up of an intergrowth of augite and feldspar, which are about of the same size. Also augite occurs rather abundantly as large crystals, which are on the average larger than the feldspars. Magnetite is an important inclusion in the augite. Considerable of the augite has been altered to a green fibrous hornblende and to chlorite. The labradorite which makes up most of the rock occurs as tabular crystals, of varying sizes. The rock seems to have a porphyritic structure, as in general there are two sets of

crystals of the augite and feldspar. In mineral composition this rock is closely allied to samples I, III, and VII.

East of the Bonanza mine there is an area of "greenstone" of irregular outline, but apparently about 2.5 miles long and nine-tenths of a mile in maximum width; that is to say, within this area all the exposures of partly decomposed bedrock along the North Fork of the Tunkey River, on Ribabaones Creek, and near the Morning Star mine, in the valley of Tunkey Ben Creek, all the residual boulders seen on two high ridges and all the soil seen throughout it indicate that it is composed exclusively of a single mass of the hard dark green crystalline. It is bordered on the northwest by an acid intrusive and on all other sides by the ordinary extrusive andesite. As it has a range of altitude of 1,000 or 1,100 feet and its contacts are apparently very steep, if not vertical, it has the field relations of a small batholith, though the appearance of the rock under the microscope suggests that it is not plutonic. The Venus vein is partly in this area. A specimen from a boulder at the forks of the creek on the Venus trail and which is identical in character with many residuals in the area was identified by Lawson as augite andesite and described as follows:

V. This rock is very similar to II, except that the rock has a coarser grain, and the augite occurs in larger crystals. The rock is holo-crystalline, and is composed chiefly of feldspars. The augite occurs as fairly large phenocrysts up to one-eighth of an inch long, and also as small flakes in the ground-mass. Alteration has affected the augite, as on the edge and in the center chlorite occurs. Secondary fibrous green hornblende occurs rather abundantly in the ground-mass. The feldspar is labradorite, and occurs in large tabular crystals. As the rock shows an attempt at a porphyritic structure, it is probably not plutonic.

The Lone Star vein is situated in a "greenstone" area whose main body is about 1.3 miles long and 1 mile wide. The rock, in a partially decomposed condition, is extensively exposed in the Lone Star mine workings, and elsewhere is indicated by residual boulders, stream gravel, and the character of the soil. Topographically, it stands up well above the neighboring rocks and includes Lone Star Hill, about 700 feet high. A narrow arm of the "greenstone" forms a low ridge across the valley of the North Fork of the Tunkey River and has produced the Bonanza Falls, 230 feet high. At the main fall the rock is well exposed and appears massive except for a little jointing. A specimen from near the foot of the fall was identified by Lawson as augite andesite and described as follows:

IV. In thin-section the rock has a greenish color, is fine-grained, and has a slight porphyritic structure, with a glassy ground-mass in which the small crystals are imbedded. The augite occurs as well developed crystals and is in an unaltered condition, except that on the edges occurs a rim of chlorite and magnetite. The feldspars are the most abundant mineral and are basic-oligoclase. They occur as large phenocrysts, and as small lath-shaped feldspars imbedded in the glassy ground-mass.

Along the Lone Star ditch there seems to be a rapid alternation of the purple-weathering andesite and the harder, dark greenish gray rock, the latter probably occurring as dikes. The Lone Star Falls is due to a small area of hard, fine-grained, greenish gray rock like that at Bonanza Falls. Thence by the trail to the old Santo Domingo arrastre only the extrusive andesite was seen, but many hard boulders of "greenstone" occur near the arrastre. Thence to the Constancia mine the andesite lava probably contains dikes of the harder rock. The hanging wall of the Siempre Viva vein as exposed in the "New" tunnel is a very hard, fine-grained, nearly black rock that has been identified by Lawson as augite andesite and described as follows:

VI. The rock is dark-colored and fine-grained. In thin-section it shows a porphyritic structure, with phenocrysts of augite and plagioclase feldspar. The ground-mass is glassy, in which occur lath-shaped feldspars, magnetite, and chlorite. The augite occurs as large phenocrysts and as small flakes in the ground-mass; it has been nearly all altered to chlorite and magnetite. Green fibrous hornblende occurs as an alteration replacement product of the augite, in long prisms in the ground-mass.

The Siempre Viva Falls is in two parts, one 90 feet high and the other 75 feet high, with rapids below; the entire fall is 220 feet. They are caused by a rib of hard, massive, greenish gray, porphyritic rock, resembling that at the Bonanza Falls except that many of the white feldspar phenocrysts have a tendency to a lath shape, giving the rock a diabasic appearance.

RHYOLITE

The northeastern portion of the district is characterized by a mass of acid intrusive rock about 4 miles long in a northeasterly direction and a mile in maximum width. It forms a lighter red and less clayey soil than do the basic rocks, but it is weathered to so great depth that I only found fresh material at two places. Both have been identified by Lawson as rhyolite. Specimen VIII is from the face of the Banana tunnel at the Bonanza mine and specimen IX from a boulder in a creek near the Hidden Treasure mine.

VIII. The rock is very light-colored, fine-grained, and is composed chiefly of feldspar and quartz. The feldspars are orthoclase and albite; these occur as phenocrysts. Quartz makes up most of the ground-mass. Pyrite is abundant, and occurs in an unaltered and fresh condition. It appears to be primary. The ground-mass is hypocrystalline, with some glass.

IX. This rock is a little coarser than VIII, and the ground-mass is not so uniform, varying from coarse to fine in different parts. It contains glass. The feldspars are the same, except that they have been somewhat altered, as they contain flakes of sericite.

Where partly decomposed the porphyritic character of the rock is not so apparent and it resembles a granite without ferro-magnesian minerals; on this account I used the field term "acid granite." At one place the border has a narrow zone of very fine-grained acid rock, suggesting aplite. Pyrite is disseminated through it, practically at the surface. The acid rock is of special interest because Lawson says that from its microscopic appearance it is not to be considered a plutonic rock, yet it certainly seems to have the field relations of a small granitic batholith that has been exposed by deep erosion. The northeastern portion of the area is crossed by a high ridge that includes the Mars, Neptune, and Venus peaks. By the time one has climbed the last in the warm humid atmosphere it appears to be about 1,100 feet high, yet rhyolite extends from base to summit. A short distance southeast of the peak the augite-andesite described under V attains nearly as high an altitude. The contact, though somewhat irregular, may be located approximately on both slopes of the ridge and is evidently very steep, if not vertical. Neptune Peak is in the rhyolite area, but the nearly equally as high Mars Peak is composed of the extrusive andesite, containing large dikes of rhyolite, suggesting apophyses from the main mass. Elsewhere near the Mars and Bonanza mines there is evidence that the contact of the rhyolite with other rocks is very steep to vertical and intrusive in nature. Mine workings, residuals, and the soil indicate that the main area is free from any other rock species, suggesting that the rhyolite is younger than the andesites.

The rhyolite forms the hanging wall of the Bonanza vein toward the southwest. The Mars and Venus veins are partly in it and the Neptune vein entirely so at the surface. They are richer in quartz and poorer in sulphides than the veins in the andesites. The Lone Star vein, though scarcely 2 miles distant, is much richer in sulphides, particularly galena. The veins of the Siempre Viva, Constancia, Concordia, and Trinidad mines are characterized by the presence of a large quantity of fine-grained specularite, and are generally rather rich in sulphides. At the

Panama mine, on the opposite side of the rhyolite area, a vein in andesite is unusually rich in galena and other sulphides. Thus I have gained the idea that veins cutting the basic rocks are richer in sulphides and other basic minerals than those in and near the rhyolite area, which I consider an indication that the rhyolite as a large mass will continue to a much greater depth than the present valley floors.

The Big Falls on the Pis-Pis River is caused by a narrow band of purple gray to nearly white, hard, flinty appearing rock that seems to rise through the andesites like a large dike trending about north 60 degrees east (magnetic). Lawson identified it as rhyolite.

X. The rock has a reddish brown color, banded appearance, and a porphyritic structure. The feldspars, which were determined as oligoclase-andesine, occur as phenocrysts, but are rare and are full of secondary sericite. The ground-mass is glassy, with an attempt at crystallization, as it is composed in places of crystallites. In the ground-mass occur lenses of quartz, feldspar, and glass, which are evidently zones of flowage. Magnetite and hematite occur on the edges of these flow zones. The hematite gives the rock the red color.

DIORITE (?)

The only other rock seen in place in the district is in an area 1,000 feet long and 270 feet in maximum width, forming the foot-wall of a portion of the Bonanza vein. I have not seen it in a fresh condition, but the general appearance of partially decomposed material suggests that it was a diorite. Diorite and ordinary biotite granite occur somewhere on the southeast border of the district, as indicated by gravels of the Tunkey River.

MISCELLANEOUS

The coarse volcanic agglomerate at Waspuc Mouth extends up the Waspuc River several miles. Beyond that it is fine grained and apparently well stratified. At Yahook Falls it contains beds of very hard, dark gray (almost black) obsidian, a thick layer of which causes a vertical fall of 8 feet. A gorge 6 miles farther up is in highly altered, rather coarse-textured, massive andesite. Five miles farther up the rock is distinctly bedded, dipping downstream 30 degrees. Thence to the mouth of the Pis-Pis River andesite lava prevails, though at one place there was noted a fine-grained lava of more acid appearance and at another a dark gray, rather fine-grained basic crystalline, suggesting the intrusive andesites. At the Yapooketan Falls the Pis-Pis River is cascading over a fine-grained, lavender rock that I think is an andesitic tuff

in gently inclined beds. The rock at the Little Falls below the Pis-Pis bodega is dark red andesite lava.

In descending the Tunkey River from Barbones, at 1½ miles the valley is constricted and passes through a range of hills of augite andesite, as indicated by the sudden appearance in the stream-bed of many boulders of hard, very dark greenish gray crystalline rock. About 4 miles in a straight line east-southeast of Barbones a rock appears that seems to be a fine-grained quartz with disseminated pyrite, possibly an altered sedimentary rock. However, farther down the river we found many boulders of the hard greenish andesite. High hills near the river and many sections abounding in these boulders indicate that even though sedimentaries may be present there is much igneous rock all the way to Tunkey. Back of the village there is much of the hard dark greenish rock, and also a light yellowish green rock that may be an altered limestone.

Pre-volcanic Sedimentaries

R. B. Stanford, the former manager of the Siempre Viva mine, says that limestone appears about 3 miles south of the mine and spreads thence southward over a broad country. At the La Luz mine shale is associated with it. He says that from the apparent relation between the limestone and lava south of the Siempre Viva mine the limestone surface may appear 1,500 to 1,800 feet below the surface at the mine. A piece of the limestone which Mr. Stanford gave me was among the specimens submitted to Doctor Lawson and was described as follows:

XI. The rock is a compact, dark-colored, fine-grained limestone, composed chiefly of large calcitic areas and a fine-grained part, which is seen to be made up of organic tests. Pyrite occurs in scattered cubes throughout the section.

My impression is that the northern border of the old sedimentary terranes trends easterly or southeasterly from the point 3 miles south of the Siempre Viva mine, and that all of Nicaragua north of it and west of the old coastal plain may be occupied by the igneous rocks described in this paper. Crawford vaguely refers to a disconnected line of limestone areas between the "granite" hills and the Wanks River, but I saw no evidence of them in the gravels of streams draining from that area, and at best they must be very limited in size. Andesitic lavas and tuffs are certainly the prevailing rocks in a great area. In the mountain regions they have been extensively intruded by other andesites and some rhyolites. Belt's "dolerytes, with bands and protrusions of hard green-

stones" in the Santo Domingo district doubtlessly correspond to the extrusive andesite and hard ribs of augite andesite in the Pis-Pis district.

Age of the igneous Rocks

In age the rocks of the Pis-Pis district are probably mid-Tertiary. This statement is based on the fact that similar rocks elsewhere in Central America are known to be of that age, and on the fact that the erosion of the country shows that volcanic activity ceased earlier than the Quaternary era or even the latter portion of the Pliocene period.

FIGURE 1.—SUPPOSED GLACIATED STONE FROM NEAR KINGSTON, IDAHO

FIGURE 2.—REVERSE SIDE OF FIGURE 1

GLACIATED STONE FROM NEAR KINGSTON, IDAHO

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SOME TERTIARY AND QUATERNARY GEOLOGY OF WESTERN MONTANA, NORTHERN IDAHO, AND EASTERN WASHINGTON[1]

BY OSCAR H. HERSHEY

(*Presented in abstract before the Society April 1, 1911*)

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Glaciation in Deer Creek Valley, Montana

The valley of Deer Creek is a deep, heavily timbered gulch heading at about 7,000 feet of altitude in the Bitter Root Range and extending about 7 miles to the Saint Regis River near Deborgia, Missoula County, Montana. Streams of ice flowing from the Chief, Diamond, Crystal, and other cirques, two of which contain typical moraine-dammed glacial lakelets, coalesced in the main valley into a glacier that during an earlier stage extended almost to the mouth. It ground the Belt quartzites and preglacial gravels into a ground moraine of light-colored clay, with

[1] Manuscript received by the Secretary of the Society December 6, 1911.

boulders, cobbles, pebbles, and sand grains heterogeneously distributed through it; this is locally known as "white clay."

After the ice had melted back to near the head of the valley, Deer Creek eroded a broad shallow channel in the surface of the white clay and floored it with stream gravel. Then in a later glacial stage the ice advanced and formed a terminal moraine across the valley about 4.6 miles above its mouth. Above this point, on account of the high grade of the valley and comparative recency of the glaciation, the creek has merely cut a narrow trench into the glacial deposit. This later glacial stage probably corresponds in age to the latest Wisconsin stage recognized in the northeastern States. It is the stage whose products are so pronounced throughout the western mountains. Evidences of earlier glaciations are usually obscure and generally either overlooked or thrown in with the phenomena of the later stage.

Of the stream gravel below the moraine, the first 3,020 yards average 64 yards wide and 2 yards deep, the next 4,250 yards average 91 yards wide and 2 yards deep, and the remaining half mile averages about 100 yards wide. The first section, as evidenced by shafts, is underlaid by white clay; the distribution of the gold in it supports the idea that it is of glacial origin. The last section is bordered by strips of glacial material that is disposed in the form of terraces, the lower ones hummocky and the highest one even. Probably this material was largely deposited by water beyond the end of the glacier. The older glacial deposit is certainly of considerably greater age than the deposit above the moraine, but I am inclined to think it represents an early Wisconsin stage rather than a stage as old as the Iowan drift sheet of the northeastern States. At any rate it is comparatively recent.

The glacial phenomena of the Deer Creek Valley are doubtless repeated in all the valleys heading high on the eastern side of the Bitter Root Range. There is a fine development of gravel terraces in that part of the valley of the Missoula River which has the summit of the range at a short distance southwest, and they are probably connected with glaciation in the short steep gulches coming down from the high mountains.

Glaciation in the Cœur d'Alene District, Idaho

In "The geology and ore deposits of the Cœur d'Alene district, Idaho," [2] Mr. F. C. Calkins has briefly described the terrace gravels and glacial deposits of the region, and the reader is referred to the map accompanying that report for their distribution. Nearly all the peaks

[2] Professional Paper No. 62, U. S. Geol. Survey Pub., 1908.

and ridges that attain altitudes of about 6,000 feet have cirques and often tarns on their northern and eastern sides. The main glacier in Canyon Creek Valley had a length of about 5 miles, as indicated by Calkins' map, and one nearly as long occupied the valley at the head of the Saint Regis River in Montana; a portion of it flowed through a pass into the Cœur d'Alene Basin. There appear to be no prominent terraces of extra-glacial material leading down the valleys from the glacial deposits. The disappearance of the small alpine glaciers has been quite recent, as the postglacial erosion has been insignificant near the head of the valleys. Although I am not able to state so from observation, it is doubtless true that the deposits include the products of the two glacial stages recognized in the Deer Creek Valley in Montana. The most conspicuous feature of these late glaciations is their confinement to relatively high altitudes. No mountain whose altitude does not exceed 5,500 feet gave rise to a glacier, and Calkins has not mapped any glacial deposit below 3,200 feet.

Kellogg System of River Terraces

IN GENERAL

The vicinity of Kellogg, in the valley of the South Fork of the Cœur d'Alene River, has the most complete system of river terrace remnants in the Cœur d'Alène district. Moreover, the writer has resided at Kellogg for over two years and has had opportunity, in connection with other work, to study these terraces in considerable detail; for these reasons they will be first described and then the terrace system traced up and down the valley.

MODERN ALLUVIUM

From the mouth of Milo Creek at Kellogg west for about 3½ miles the floor of the valley averages about 800 yards wide. Before being largely buried under tailings from the concentrating mills of the great lead mines of the district, the floodplain was apparently a bed of moderately coarse gravel overlaid by several feet of dark brown sandy silt. The coarsest gravel along the present channel has few boulders 12 inches in diameter. Igneous material is very inconspicuous, probably not exceeding 1 per cent of the gravel. I suppose the depth of the alluvium to be not more than 20 to 50 feet. The fall of the valley is about 30 feet per mile near Kellogg.

THIRTY-FOOT TERRACE

This terrace is developed along the south side of the valley from near the mouth of Milo Creek to near the mouth of Deadwood Creek, a dis-

tance of 1 mile. These streams have built their alluvial fans of coarse gravel on it, but between the fans it remains in a finely preserved condition. The north border is a steep bank with lobate outline produced by erosion by the Modern river. The height varies from 27 to 29 feet above unburied remnants of the Modern floodplain, and the width of the terrace varies from 80 to 150 yards. It descends westward down the valley at a rate only a little less than the Modern floodplain.

No bedrock appears in the bank, and this terrace is apparently entirely built of unconsolidated materials, chiefly brown stratified gravel like that of the Modern alluvium except that it has few cobbles 6 inches in length and practically no boulders. The unique feature is the upper deposit, a structureless bed of non-pebbly light brown silt 2 to 6 feet thick. The line between the gravel and silt is rather sharp and apparently undulating. The silt is composed of angular and subangular grains of quartz and other minerals occurring in the rocks of the region and was probably derived from the soil of the district and deposited by the river at flood stage. It is relatively impervious to water and gives rise to a thin and rather sterile soil, contrasting strongly with the fertile dark brown soil at the surface of the Modern alluvium.

There is probably a small remnant of the terrace at the mouth of Elk Creek, 1½ miles above Kellogg, and another at the mouth of Government Gulch, 2 miles west of Kellogg. In both the gravel is overlaid by 2 to 6 feet thickness of pebbleless silt.

The age of the deposits in this terrace is indicated by the subsequent erosion. Opposite the terrace at Kellogg the river has eroded a valley 900 yards wide and at least 35 feet in average depth, and except for the few small remnants described above it has practically destroyed the deposits for many miles above and below the terrace at Kellogg. They belong to a relatively late epoch of the Quaternary Era, but are much older than the glacial material in the cirques of the high mountains. It is my impression that this 30-foot terrace is of the same age and due to the same conditions as a low terrace at the mouth of Deer Creek Valley in Montana, belonging to the earlier glacial stage there recognized.

SIXTY-FOOT TERRACE

At a small remnant of this terrace at a railway cut between Deadwood and Government gulches the bank to a height of 27 feet is Prichard slate overlaid by 8 feet thickness of coarse river gravel abounding in cobbles and small boulders. The original terrace surface is present farther back along the wagon road. A better remnant occurs at the Sweeny mill on the east side of the mouth of Government Gulch. The Prichard

slate rises 40 feet above the Modern floodplain and the original surface of the terrace at the north edge was about 20 feet higher. The uneroded surface rises toward the south at first 2 degrees and then steeper on the slope leading up to the next terrace. The deposit seems to comprise several feet of coarse cobbly and even bouldery gravel and over this ordinary gravelly alluvium. This is overlaid, near the foot of the slope leading to the next terrace on the south, by a bed of non-pebbly silt several feet thick.

This is the youngest of a series of gravel-capped rock benches and has no particular significance, as it merely marks a local vicissitude in the down-cutting of the valley. There are traces of the same terrace farther down the valley, but this is not a prominent terrace horizon and will not be considered in the further discussion of the subject.

TWO-HUNDRED-FOOT TERRACE

This terrace is well developed along the south side of the valley from Kellogg to Grouse Creek as a series of flats separated by the broad canyon-shaped valleys of Deadwood and Government creeks and by several narrow gulches. Bedrock generally rises in the terrace till within 30 to 40 feet of its surface. In the most easterly flat (back of the Kellogg hospital) the first bed over the bedrock appears to abound in waterworn boulders, many of which are 18 inches in longest diameter. This is a much coarser river deposit than any seen lower. Above this there is a light brown sand and silt with scattered cobbles, but not much fine gravel. The uppermost part of the deposit is largely a light brown sandy silt. The remarkable feature of this terrace is the boulders scattered over its surface, apparently weathered out from the upper part of the deposit. They are not numerous, but widely distributed.

Besides the local quartzites there is an unusually large percentage of igneous rocks, including greenish crystallines that might have been derived from dikes in the drainage basin of the river, a granite of doubtful occurrence in the basin, and a pink quartzite not known from the Belt rocks of the region. The largest boulder, which has a maximum diameter of 30 inches, consists of a porphyritic granite, resembling the monzonite near Gem. These boulders reach an altitude of 250 feet above the river or 2,500 feet above the sea. No boulders were observed on the next flat west (which is 200 yards wide), probably because of the thick brush, and near Deadwood Gulch the horizon of the granite boulders is buried under an old alluvial fan of Deadwood Creek. Government Creek has trenched across the terrace a steep-walled canyon about 175 yards wide

and 150 feet deep. This is cut through the gravel into the Prichard slate.

The gravel terrace on which the Kellogg cemetery is situated is 250 to 300 feet above the river and its surface slopes 5 degrees toward the north. There is apparently a distinct channel in the bedrock under the terrace; it is separated from the present river channel by a ridge of Prichard slate. This slate rim-rock ridge, cut by numerous transverse gulches and canyons, is present between the old and new channels for about 2½ miles east from the cemetery. The original filling of the old channel by river gravel apparently long preceded the development of the 200,foot terrace. An important remnant of the latter, occupied by a ranch about a mile above Kellogg, has a granite boulder nearly 3 feet long, several smaller granite boulders and cobbles of several varieties of granitic rocks. They have an altitude of about 300 feet above the river or 2,650 above the sea. A small remnant of the gravel of the 200-foot terrace occurs on the north side of the valley at Kellogg.

This terrace certainly presents some interesting problems, the chief of which are the origin and mode of transportation of the granite boulders; but we must get acquainted with more facts concerning the terraces of the region before we can discuss them.

SIX-HUNDRED-FOOT TERRACE

The principal remnant of this terrace, about 600 yards long, parallel to the valley, and 300 yards wide, is occupied by the Page ranch, immediately west of the valley of Milo Creek. The surface is quite undulating because of much erosion, but the unconsolidated material in the small ridges is at least 40 to 50 feet thick. The water-worn boulders that weather out around the borders of the terrace are chiefly of local quartzites and no granite or other igneous rocks have been seen among them. My impression is that the lower part of the deposit is very coarse and includes boulders 3 feet in length. Elsewhere the gravel of this terrace is inclined to be relatively fine, and probably the boulder deposit under the Page ranch was formed near the mouth of a tributary valley. It is a characteristic of this terrace that its inner border is usually obscured by debris from the neighboring mountain slopes.

The nearly even crested ridge at the surface of the deposit in the old buried channel east of Elk Creek Valley is 50 feet higher than the Page ranch. The corresponding ridge over the gravel in the old channel immediately west of the canyon of Big Creek has a flat of considerable extent at a level of about 550 feet above the river, but the highest portion of the deposit is 700 feet above the river. I agree with Calkins that

the old channel was filled to a depth of 500 feet. The characteristic feature of the deposit is its relative fineness, there being much rather fine well-worn gravel and much sand. The old channel, whose floor at Kellogg was about 100 feet above the present river level, emerges into the present river valley on the western side of the Kellogg cemetery. On the south side of the deep channel a much shallower channel was eroded in the bedrock and filled with gravel. A small remnant of this deposit caps a knoll on the ridge immediately east of Government Gulch at the same altitude as the Page ranch. In fact the 600-foot terrace marks the floor of the valley at the completion of the deep valley filling.

ELEVEN-HUNDRED-AND-FIFTY-FOOT TERRACE

The chief remnant of this terrace is on a narrow spur between Milo and Elk creeks, about a mile south of Kellogg. In a flat of several acres extent the gravel may be 50 or 100 feet deep. It is relatively coarse and abounds in cobbles. This terrace is the highest of the Kellogg system, and probably represents a valley floor that was broader than in any subsequent stage and was bordered by high mountains, not much less rugged than at the present day.

Calkins has pointed out that the general uniformity of elevation of the high ridges of the Cœur d'Alene Mountains suggests a dissected peneplain at about 6,000 feet of altitude, but I do not consider the evidence to be sufficiently strong to be worthy of confidence. The South Fork of the Cœur d'Alene River excavated at Kellogg a valley about 4,000 feet deep. The 1,150-foot terrace marks a local vicissitude in the deepening of this valley and has no particular significance otherwise. Then the river aggraded this deep valley until it was filled with gravel, sand, and silt to a depth of 500 feet. The valley was then much wider than at any subsequent stage and the river flowed near its northern side. A change in conditions caused it to actively erode the valley floor. East of Kellogg as far as Big Creek the new channel is largely cut in Prichard slate and indicates considerable age for the 600-foot terrace. When the new valley had been cut down 400 to 450 feet, it was floored by a relatively coarse alluvium 30 to 40 feet thick. Then the boulders of granite and other igneous rocks were introduced and scattered over the valley floor. After that the river deepened the new valley 250 to 350 feet, partly in gravel but chiefly in Prichard slate. It then aggraded the valley to a height about 30 feet above the present river level, then nearly removed this new filling and finally deposited the Modern alluvium.

It is to be noted that the river tended to cut each canyon beneath the northern portion of the floor of the next higher canyon—that is, to mi-

grate northward. This might have been due to a progressive northward tilting of the country, but I believe it had a different cause. In the vicinity of Kellogg the mountains on the south of the valley are much higher and more abrupt than those on the north. As a consequence the debris that worked down from them and the gravel deposits that came out of the gulches were much stronger than those from the north and forced the river toward the north. It is significant that up and down the valley where this distinction between opposite sides of the valley breaks down the terrace remnants are no longer practically confined to the south side.

Terraces east of Kellogg Region

The 600-foot terrace is represented by gravel at an elevation of 700 feet above the river on the first ridge east of Big Creek, a small remnant on the next ridge east, and a gravel deposit at 650 feet a little over a mile east of the mouth of Big Creek. A small area of gravel on the ridge west of Two-mile Creek, at an elevation of 500 feet above the river, is probably a remnant of the deposit under the terrace. One and one-half miles east of Osburn the old valley is obstructed by a gravel deposit at least several hundred feet thick, compelling the river to pass through a short section of new valley on the south. It reaches 550 feet above the river. There is much fine gravel and near the highest point an excavation shows yellow and buff sand. No boulders of granite or other igneous rocks were seen in connection with the deposit. Though much eroded, the gravel was not cut down enough to permit the 200-foot terrace level to pass through the old valley. The great width of the present valley at Osburn is due to the fact that there the old and new valleys coincide.

Remnants of the 200-foot terrace occur at 350 feet above the river on the first ridge east of Big Creek, at 300 feet on the west side of Terror Gulch, and at 300 feet in a gently rolling gravel flat on the east side of Terror Gulch. No boulders of granite or other igneous and metamorphic rocks were observed in connection with them. This is especially remarkable in the case of the last remnant, which is of sufficient extent to be occupied by a farm, whose broad fields and piles of boulders along the fences make conditions unusually favorable for observation. It is evident that the granite boulders on the 200-foot terrace terminate about a mile east of Kellogg, and that they were not derived from some point up the valley. This makes their presence more remarkable.

The 1,150-foot terrace stage may be represented by an extensive gravel deposit, reaching an elevation of 1,250 feet above the river about 1½

miles north of Wallace, and by the higher part of a long narrow gravel deposit mapped as capping a ridge between Nine Mile and Canyon creeks. A group of terrace gravel deposits along the south side of the valley from Mullan east only attain an altitude of several hundred feet above the river and can not be directly compared with the Kellogg system, as there is too long an interval between.

Terraces west of Kellogg Region

Patches of old river gravel on the first ridge west of Government Gulch represent the 600-foot-terrace horizon. A more extensive remnant near Corrigan Gulch has been eroded into a system of gently rounded ridges, consisting mainly of a moderately fine gravel, though some cobble beds appear locally. There is in the topography a strong suggestion of an old channel crossing several of the neighboring rock ridges, and this is probably the result of erosion partially reopening an old channel. The valley floor at the completion of the deposit was at least half a mile wide.

On the northern border of this rolling gravel country there are two remnants of the 200-foot terrace. They are on a level with a sag, 500 yards wide, that leads from Corrigan Gulch to Pine Creek Valley. The gently undulating floor of the sag is underlaid by a deposit of apparent river gravel, with an occasional small boulder of granite or other igneous rocks. A deposit of well rounded, moderately fine river gravel that extends up the slope on the south to at least 100 feet higher than the gap probably represents the gravel under the 600-foot terrace. This gap is in line with a narrower but otherwise similar gap between Pine Creek and Kingston. Another gravel-floored gap occurs between Kingston and Cataldo. They are evidently sections of the deep old channel that were filled to a depth of 500 feet and partly reexcavated since. The South Fork of the Cœur d'Alene River has a new course on the north of the old valley from the mouth of Corrigan Creek to near Cataldo. The new valley between Pine Creek and Enaville at the mouth of the North Fork is a narrow crooked rocky gorge separated from the old valley by a quartzite ridge that may attain an elevation of 600 feet above the river. The first railroad built in the region followed the old valley in preference to this gorge. Between Enaville and Kingston the river occupies the old valley of the North Fork, but below Kingston it passes through a series of gorges that are a little narrower, much deeper, and steeper walled, and hence more youthful in appearance than the corresponding portions of the old valley.

On a rock bench 125 feet above the river at the mouth of Pine Creek a thin sheet of light brown sandy silt has scattered over it many cobbles and small boulders up to 2 feet in length of quartzite and igneous rocks, including the varieties of granite and basic crystallines usual to the 200-foot terrace. An 8-inch boulder is of fine-grained gneiss. The bouldery deposit extends up the slope back of the rock bench to at least 50 feet above it. Igneous material constitutes at least 25 per cent of all cobbles and boulders over 3 inches in diameter. No fine gravel appears.

The old river valley between Pine Creek and Kingston is about 500 yards wide. The northern part of its floor is a shallow U-shaped trough about 400 feet wide, under which there is a bed of argillaceous material abounding in rock fragments of all sizes up to small boulders. Most of them are of local material, largely Cataldo quartzite,[3] in an angular and subangular condition. There are some water-worn boulders and cobbles of quartzite, but the most characteristic portion of the material is the igneous rocks. Various varieties of granite and diorite are common. There are basic crystallines, fine-grained gneisses, and pegmatites. Many of the well rounded, dark gray quartzite pebbles have probably come with the igneous rocks. When I first discovered this deposit in the summer of 1909, I was impressed by its having some glacial characteristics, and I even thought I found traces of glacial striation on some of the subangular rock fragments. In fact on my last visit I found a 2½-inch quartzite fragment apparently faceted and scratched on two sides and less clear scratches on other pebbles. However, as they occur on the slope of an old railway cut now used for a wagon road, I am willing to ignore these apparently glacially striated stones.

In a 20-foot cut the boulder clay is underlaid by a succession of thin beds of horizontally stratified fine argillaceous sand and silt of blue gray, reddish brown, yellowish brown, and white colors. This I believe belongs to the deep valley filling. On the south of the valley several nearly flat-topped ridges of Prichard slate are crossed by a gentle depression. They probably represent the rock bench under the south por-

[3] The term "Cataldo quartzite" is temporarily applied to a member of the Belt series of formations, which was not recognized by Ransome and Calkins in their report on the Cœur d'Alene district, as it is apparently poorly represented in that district. It consists chiefly of heavy beds, in part cross-bedded, of lilac-colored medium-grained quartzite, differing in appearance from any quartzite above the Prichard. With this are beds of greenish, finer-grained sericitic rock. Its thickness is at least 1,000 feet. It evidently underlies the Prichard slate. Beginning a little above the mouth of Pine Creek, it is exposed over a great area, thence nearly to the station of Rose Lake. It also occurs near the town of Tekoa, in Washington, and it is my impression that it will be found generally along the border of the Archean gneisses and granites, it being apparently the basal member of the Belt series; it probably corresponds to the Creston quartzite of Daly. Its outcrops have a light gray color and it gives rise to a stony sterile soil.

tion of the 600-foot terrace. Curiously, granite boulders occur in the shallow valley between these ridges at about the level of the summit in the gap. Large angular fragments of granodiorite near the summit of the railroad grade are probably the result of blasting several boulders at least 4 feet long.

A narrow terrace about 150 feet above the river, southwest of Kingston, has many cobbles and small boulders of granite and other igneous rocks and represents the 200-foot terrace. One granite boulder is 4 feet long. There is one subangular 14-inch fragment of coarse gneiss (with plates of white mica one-half inch long) of a decidedly Archean aspect. A 40-inch granite boulder is imbedded in the soil 300 or 350 feet above the river. At 500 or 600 feet above the river there is a shallow saddle crossing a ridge in line with similar saddles on ridges east and west, doubtless representing a partially reexcavated shallow channel under the southern portion of the 600-foot terrace. Gravel continues to the top of a small rounded peak, 600 or 700 feet above the river. From its top one can see many ridges of similar height, whose summits roughly outline the floors of broad valleys extending down the river and up its two forks. The so-called "old valley" is the deep channel that was filled to a depth of at least 500 feet to the level of these broad valley floors. The main river shifted to the north side of the broad valley, and when it cut down again it encountered buried rock ridges, through which it excavated the gorges of the new valley.

The section of the old valley between Kingston and Cataldo is about 300 yards wide at its narrowest part and its floor is about 150 feet above the river at Cataldo. The uppermost deposit near the summit is a bed of subangular local debris, local conglomerate, water-worn cobbles, and small boulders and the usual sprinkling of granite and other foreign rocks, including gneiss and mica schist. On the surface igneous rocks constitute 10 to 25 per cent of all boulders and cobbles over 3 inches in diameter. On the western slope we get below the gravel bed, and the road bed imperfectly exposes a very fine-grained orange-colored non-pebbly silt. However, boulders continue to be scattered over the surface. In an orchard there is a boulder of granodiorite 9 feet long, 8 feet wide, and projecting 4½ feet above the soil. (The mountain behind is of quartzite.) Certainly this huge boulder was not brought by ordinary river action. I can only conceive of ice as the agency that brought it to its present position over a soft silt bed.

Farther down the slope the silts are exposed in a railway cut to a thickness of 18 feet. They are extremely fine grained, finely laminated, and absolutely non-pebbly. The colors are bright, mostly pink and yel-

low, with some red, brown, orange, and cream color. In a railway cut about 1½ miles below Cataldo the bulk of the material is an extremely fine silt of white color, though orange, pink, and yellow tints appear in places. It is made up of subangular grains of colorless minerals, chiefly quartz. A silica determination made by Mr. William McM. Huff at Kellogg yielded 93.8 per cent insoluble (presumably silica), the remainder chiefly alumina. A bed of white gravel and brown conglomerate is associated with the silt; the gravel and silt combined have an exposed thickness of 35 feet and reach a height of 53 feet above the low-water stage of the river. A bed of younger and rather coarse river gravel at the top of the bank forms a terrace whose highest part is about 100 feet above the river. Granite and other igneous small boulders and cobbles are scattered on the terrace and extend high on the mountain back of it.

The old valley seems to run squarely into the present broad valley at Cataldo. Thence for about 2½ miles the valley is a flat-floored basin 1 to 1½ miles wide. At the west end the river leaves the broad old valley and enters a newer valley on the south, which it follows to Rose Lake station. The old valley is obstructed by a broad undulating north-south ridge, about 150 feet high, consisting of much fine, well-worn gravel and variegated silts; boulders and cobbles largely of granite and other igneous rocks are scattered sparingly over the higher slopes. A broad transverse valley on the west of this ridge was cut into the gravel deposit to a depth somewhat below the present river level at Dudley and was subsequently occupied by an arm of Cœur d'Alene Lake. The river built a dike across the south part of the valley, forming a small isolated lake that in time became filled by muck to form the present flat valley floor. On the slope north of the valley there is a granite boulder 6 feet long and 4 feet wide, and near by another boulder 3 feet long.

Between the extinct lake and Rose Lake the old valley, about a mile wide, is occupied by an undulating country 100 to 200 feet above the river at Rose Lake station. The low ridges consist mostly of old river gravel and sand, some cemented by limonite to brown conglomerate and coarse sandstone; there are also traces of the white silts. Cobbles and boulders up to 4 feet in length, of granite and other igneous rocks are plentifully scattered over the surface of the ridges. On the north border of the valley they are part of a deposit consisting chiefly of angular and subangular local debris, with a number of well-worn small boulders of hard dark gray quartzite that are apparently faceted and well scratched as though by glacial action. This deposit forms an imperfect shoulder

at an elevation of probably 300 feet above the river at Rose Lake station, above which the debris is exclusively of Cataldo quartzite.

West of Rose Lake station granite boulders are scattered along both sides of the valley almost down to the river level. On the north side, a little over a mile west of the station, there is a boulder of granodiorite 5 feet long, 4 feet wide, and projecting 3½ feet from the ground. About 1½ miles north of Lane there is a granodiorite boulder 6 feet in diameter and 3 feet high. The largest granodiorite boulder in Lane is 6 feet long, 5 feet wide, and 3 feet high above the soil. Granite and associated igneous debris are plentiful on the slope back of Lane to a height of 150 feet above the river and are sparingly scattered up to a rock bench whose height I estimated at 400 feet above the river. On another remnant of the rock bench there is a 30-inch boulder of granite. Several small boulders of basalt are the first representatives of that rock that I have seen in connection with the granite boulders. These rock benches probably represent the 600-foot terrace, being the rim-rock of the deep old channel that at this point probably extends much below the present river level. Near Lane station there is a well that penetrates river gravel and yellow sandy silt, such as are found in the bottom of the old valley above Rose Lake.

Detailed investigation was not carried farther down the valley, but I have become acquainted with its general character through railway journeys. At Medimont, about 4 miles from Lane, basalt appears in the broad valley at about the river level, and thence to Cœur d'Alene Lake, basalt is frequently seen along the lower slopes of the mountains. In one or two places it seems to form a distinct terrace at about the height of the rock bench at Lane. It is evident that this basalt occurs in the old valley that was excavated and filled to form the 600-foot terrace. Its introduction into the western portion of this valley must have obstructed the drainage and caused the accumulation of unconsolidated deposits in the valley east of it. The absence of any such accumulation in the reopened valley and the size of the canyon excavated in the lava filling of the western portion of the old valley indicate that the lava probably entered and obstructed the old valley immediately after it had been cut down to its maximum depth. Indeed there can be little doubt that it was the presence of the lava that caused the deep accumulation of fine gravel, sand, and silt in the old valley. The lava barrier rose more rapidly than the river could aggrade its channel and a lake was formed—Lake Latour. This was of an extent and depth comparable with the present Cœur d'Alene Lake. The white and variegated silts (Latour formation) were laid down in it. There is evidence of their

extent to a point several miles above Kellogg. Much of the fine gravel and sand in the old channel is probably a delta built into the lake by the river. Finally, the period of volcanic activity came to an end, the lake was filled by sediment, and the river meandered on a broad valley floor, which is now represented by the few remnants of the 600-foot terrace. Hence the age of this terrace may be nearly the same as that of the termination of the lava flooding.

Early Glaciation in northern Idaho

I consider the granite boulders of the 200-foot terrace evidence of glaciation somewhere not far distant from the Cœur d'Alene Valley at the time of their distribution in the valley, but the question remains as to whether they were carried by a glacier or by ice floating in a lake. They came from some region where granite and other igneous rocks form a much larger percentage of the total area of the rock formations at the surface than in the Court d'Alene region. The gneisses that resemble Archean rocks may be from contact metamorphic zones in the Belt formations, but no gneisses are known from the Cœur d'Alene Mountains.

The strongest evidence of direct glacial action in the valley lies in the considerable masses of angular and subangular local debris with which the boulders are associated in places. They resemble lateral moraines, but it is difficult to conceive of a shallow narrow tongue of ice extending 20 miles up the valley and transporting boulders to its end. The strongest evidence against actual glaciation I believe to lie in the absence of basalt in the material above Lane. A glacier coming up the valley could not have failed to tear some of the basalt from its bed and distribute it as far as the granite boulders were carried. Hence, I am inclined most strongly at present to favor the hypothesis of a lake and floating ice as the mode of transportation of the boulders. It implies that some great glacier coming down from high mountains in the north obstructed the outlet of Cœur d'Alene Valley and formed an extra-glacial lake, probably much larger than the present Cœur d'Alene Lake. Boulder-bearing icebergs broke from the front of the glacier and were driven up the lake by the prevailing westerly winds to melt and drop their burden of glacial debris on the lake floor. The boulders are known to have, roughly, an altitudinal limit of distribution, and a more thorough search might develop a regular line as their upper limit. The ice barrier may have been no more distant than a few miles below Lane, but is likely to have been somewhere in the region of the north end of Cœur

d'Alene Lake, beyond the main basalt area. The lake must have existed for a very short time, for no extensive typical lacustrine deposits were made in it. The deposits of local debris bearing granite boulders may have been formed by shore ice or wave action along the steep slopes during the rising and falling of the surface of the lake, but this wave action was not continued long enough at one level to form a recognizable beach.

The most interesting feature of this glaciation is its relatively great age. The best measure of this is the size of the rock canyon excavated in Prichard slate by the river between Kellogg and the mouth of Big Creek subsequent to the abandonment of the 200-foot terrace as the valley floor. This may average 300 feet deep and 500 feet wide at the bottom. Below Pine Creek the river has cut at least 125 feet deep into hard Cataldo quartzite. If the bouldery deposit had been formed after part of this rock-cutting had been accomplished, I hardly think it would have been so completely removed that none would remain in the canyon or in the wide valley below Kellogg. There are no granite boulders on the 600-foot terrace. Unquestionably the boulder deposit is very much older than any glacial phenomena recognized in the high valleys of the Bitter Root Range; it is probably as old as any drift-sheet in the Mississippi Basin.

Origin and Age of Cœur d'Alene Lake

Cœur d'Alene Lake is a long, narrow branching body of water occupying a steep-walled mountain valley which is the continuation of the new or post-basalt valley of the Cœur d'Alene River. Near the southern end of the lake the basalt forms terraces between the lake and the higher mountains of pre-Tertiary rocks. It is my impression that the lake has been produced, as suggested by Ransome,[4] by the damming of an old mountain river valley by the accumulation of glacial overwash gravels derived from a glacier retreating northward along the Purcell trench. In the city of Cœur d'Alene, at the north end of the lake, the gravel plain is overlaid by a bed of brown sand which slopes toward the lake. The Spokane Valley above Spokane is floored by this broad, nearly level gravel plain; the gravel in places is rather coarse and contains many small boulders. The Spokane River flows in a shallow trench which in many places is no wider than the stream, suggesting the Upper Mississippi River in central Minnesota, where it is flowing in a narrow trench cut in gravel plains of Wisconsin age. At Post Falls the Spokane

[4] Professional Paper No. 62, U. S. Geol. Survey Pub., p. 18.

River, in cutting down into the gravel, encountered a buried rock ridge near the south side of the valley, and at Spokane Falls it has not yet cut its canyon through a buried basalt ridge. The size of the canyon below the falls indicates that the gravel filling of the valley is Wisconsin in age. Hayden Lake also occupies a mountain valley seemingly dammed by this geologically very young gravel deposit.

The youth of Cœur d'Alene Lake is further testified to by the fact that the streams flowing into it have failed to fill its basin with sediment. The Cœur d'Alene River has built a delta from the original head of the lake near Cataldo, 25 miles, to near Harrison. This consists largely of natural dikes bordering the deep, narrow channel of the river. Behind the dikes are marshes and lakes, including Rose, Killarney, Hidden, Medicine, Cave, Swan, Black, Blue, Thompson, and Anderson lakes. The most easterly of these lakes occupies a valley of considerable extent eroded after the distribution of the boulders marking the earliest glacial stage.

Valleys of Clearwater Country, Idaho

In the region of the South Fork of the Clearwater River, in Idaho County, Idaho, most of the higher mountains are long, relatively even-crested, moderately smooth ridges that may represent an ancient peneplain.[5] The highest peaks, such as Pilot Knob (altitude, 7,160 feet), Buffalo Hump (altitude, 8,320 feet), Anderson Butte (altitude, 6,800 feet), Gospel Mountain, and Umbrella Butte, seem to rise above the level of the long, smooth ridges and may represent monadnocks on the peneplain. The main streams eroded broad, basin-like valleys to a depth of several thousand feet below the old peneplain level, and floored them by wide and in places thick deposits of gold-bearing river gravels. The South Fork of the Clearwater River, where I saw it in the vicinity of Newsome and Ten-mile creeks, is entrenched in a narrow, rocky canyon which has been cut beneath the gravel-floored old valley to a depth of probably 800 to 1,000 feet. It resembles the Pleistocene canyons of the Sierra Nevada region and is probably of the same age.

The river passes out of the mountain region into that of the "prairies," or plateaus, which are portions of a great, gently undulating basalt plain that merges with the great lava plain of the eastern Washington wheat region. I did not follow the valley of the South Fork of the Clearwater so as to determine whether the floor of the broad upper valley

[5] Lindgren also entertained this view. See Professional Paper No. 27, U. S. Geol. Survey Pub., 1904.

merges with the lava plateau surface, but my impression is that in a general way it does. At any rate, the mountains which were visited by me are of Archean granites, gneisses, schists, etcetera, and distinctly rise above the lava plateaus as they do above the old valley floors. Hence the presumed peneplain represented by the crests of the higher ridges is much older than the lava. The river crosses the plateau region in a deep, narrow, rocky canyon whose general appearance suggests an age similar to that of the canyon in the Newsome Creek region. The walls are generally of basalt, but in places older rocks appear under it, indicating that the lava overlies a hilly surface. Tributary streams have corresponding canyons. There is evidence that, in addition to the canyon cutting, there has been erosion on the plateau surface to a depth in places of several hundred feet.

Plains and Valleys of eastern Washington

The eastern Washington and Idaho wheat country, as seen from an isolated mountain north of Tekoa, in Whitman County, Washington, appears to be a sharply undulating plain, characterized by rounded hills rather than long, broad swells. The range of altitude between the main hill crests and the streams in the narrow valleys may average several hundred feet. In the distance the hilltops merge into an apparent plain, though not an absolutely level one. It is broken by a prominent peak, Steptoe Butte, and by several lesser elevations in the vicinity. At Garfield the country is more sharply wrinkled, but the hills do not much exceed 100 feet in height. The soil is dark brown in color and free from fragments larger than grains of sand. The subsoil is the light brown siltlike material produced by the decomposition of basalt. Fresh railroad cuts near Tekoa show 20 to 40 feet depth of this material. Dark brown basalt appears in low bluffs in some of the valleys. It is to the great depth of the fine and relatively homogeneous residuum of the basalt that the hills owe their smooth contours. The topography is like that of a long-eroded, loess-covered upland region in the Mississippi Basin.

This great "plain," which is a plain by reason only of the small range of altitude of its hilltops, passes into the reentrants between the spurs of the Cœur d'Alene and Clearwater groups of mountains on the east. The line of demarkation between the plain and the mountains, as seen from such elevations as the mountain near Tekoa, is a sharp one, but at closer range the undulations of the plain merge into the greater undulations of the mountains. The mountain north of Tekoa consists of

hard gray quartzite, apparently Cataldo. Other western spurs of the Cœur d'Alene Mountains are evidently of the metamorphic rocks, at least in their higher parts. Without a detailed study, I can not say how high the basalt rises on the flanks of the quartzite mountains, but I think it is true that in a general way the undulating plain of the wheat country represents the original lava plain and the mountains which rise above its eastern border are of older rocks that were never lava-covered.

The new Oregon-Washington Railway and Navigation Company's cut-off between Spokane and Harrison leaves Cœur d'Alene Lake in a canyon cut in lava, which it presently leaves and traverses the gently rolling plateau surface. Then it ascends through a range of low hills in which the cuttings are in granitic rock, and comes out on a broad, gently rolling plain which seems to merge into the great lava plain of eastern Washington. The Mica Range rises abruptly on the northern side of the plain; the railroad descends to the broad valley of the Spokane River through a narrow, crooked valley cut in light gray micaceous rock.

Between Harrison and Tekoa the railroad ascends one of the canyons cut into the lava near Cœur d'Alene Lake to a low ridge on the eastern border of the great lava plain, and thence descends into a shallow valley excavated in the lava on the western slope from the divide. I have no doubt that the lava about the south end of Cœur d'Alene Lake consists of the same sheets as underlie the eastern Washington wheat country; in other words, that the uppermost gravel of the 600-foot terrace of the Cœur d'Alene Valley may be practically the same stratigraphic horizon as the highest basalt sheet in the Tekoa region.

The Great Northern Railway west of Spokane climbs out of the valley on to the lava plateau on the south, and traverses its gently undulating surface at altitudes mostly between 2,300 and 2,500 feet above sealevel. From Harrington (altitude, 2,167 feet) the rolling plain descends westward to about 1,300 feet at Wilson Creek, and thence for over 40 miles there is no material descent. The railroad is generally below the level of the rolling plain, in shallow valleys and small canyons which increase in number and depth as the Columbia River bluff is approached. Many of these small valleys are bordered by basalt bluffs, but the higher divides are smooth and must have a deep soil, for they are largely under cultivation. Finally the railroad descends into the canyon-like valley of the Columbia River, crossing the stream at an altitude of 588 feet. The Columbia River lava appears to be upturned on the west side of the river, but soon gives place to older rocks.

All over the Columbia Basin the essential features are: A pronouncedly undulating surface, with broad smooth ridges or small

rounded hills, in which the lava is decayed to great depth, and stony tracts and basalt bluffs along the streams and main valleys. There are few extensive flats, and such as occur are floodplains of the streams or areas in which the decomposed basalt has been swept away down to some especially resistant lava sheet. The latter is probably the origin of a relatively flat plain, about 20 miles from Spokane, on the Palouse branch of the Northern Pacific Railroad, made up of very low flat-topped rocky tables of basalt separated by broad swales, many of which have shallow lakes in the rainy season. The larger streams, such as the Columbia, Spokane, and Snake rivers, generally flow in steep-walled valleys or canyons trenched beneath the floor of the uplifted and tilted basin plain except where, in the west central portion of the basin, the plain descends nearly to the level of the Columbia River. On the north and east sides outliers of older mountains rise like monadnocks from the plain; but I am not certain of the relation between the Cascade Range of central Washington and the plain of the Columbia Basin.

The Columbia River (Yakima) lava has been shown by Smith, Merriam,[6] Sinclair, and others to be mainly of early Miocene age, as that term is used by the students of vertebrate paleontology, although elsewhere in the Pacific Coast country the outpouring of basalt continued into the Pliocene period. The highest sheet in the basin is probably middle Miocene in age. The earlier lavas may not have attained such an elevation along the eastern border of the basin as to have affected the drainage of the valleys in the Idaho mountains; hence the deep valley filling under the 600-foot terrace in the Cœur d'Alene Valley may be entirely middle Miocene in age. The gravel of the 1,150-foot terrace at Kellogg may be rather early Miocene. There may have been an interval between the close of the volcanism and the orographic disturbance which, by tilting the lava plain, inaugurated the erosion of the canyons. The larger canyons, as already pointed out in the case of the Clearwater, are comparable with the Pleistocene canyons of the California mountains and probably of the same age. They make it reasonable to attribute the uplift and tilting of the lava plain to the period of orographic disturbance of wide extent in the Pacific Coast country which opened the Quaternary Era.

Summary

The Tertiary history of the region discussed opens with the erosion of deep, broad valleys in the Clearwater region of Idaho and deeper and

[6] Tertiary faunas of the John Day region. Bull. Dept. Geol., Univ. Cal., vol. 5, p. 193.

narrower valleys in the Cœur d'Alene Mountains (giving the latter the unique distinction among western mountains of having been nearly as rugged in middle Miocene time as today), with a great low plain on the west of the mountains. This plain was flooded with basalt lava, which gradually rose against the western slope of the Idaho mountains, and in the middle Miocene period so obstructed the Cœur d'Alene Valley that a lake was formed beyond the lava barrier and the deep old valley filled with sediment to a depth of 500 feet. At the close of the Pliocene period the Idaho mountains were uplifted, the lava plain tilted southwesterly, and the streams began to cut new canyons. When the Cœur d'Alene River had trenched its new valley to a depth of about 400 feet, a glacier advanced across the valley somewhere below Lane and formed a lake of very short duration, in which floated icebergs laden with glacial debris. At this time probably between two-thirds and three-fourths of the Pleistocene period had passed. When the ice retreated, the river cut its valley 100 to 350 feet deeper, locally forming river terraces. Near the end of the Pleistocene period alpine glaciers formed in the Bitter Root Mountains of Montana and Idaho and ran short distances down the valleys. Valley trains of over-wash gravels led down the main valleys, such as the Saint Regis in Montana and the South Fork of the Cœur d'Alene in Idaho. Then the ice largely melted away from the high mountains and the valley trains were nearly removed by erosion. Finally, the glaciers advanced again, though to a less distance than formerly. Their valley trains are largely buried under the Modern alluvium except that of the Spokane Valley. This obstructed the Cœur d'Alene Valley and formed the present Cœur d'Alene Lake. The lake was originally a little higher than at present, as evidenced by the bed of sand in the city of Cœur d'Alene. At the opening of the Recent period the glaciers disappeared and the rivers began to build up the Modern floodplains, including the delta of the Cœur d'Alene River.

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DEFLATIVE SCHEME OF THE GEOGRAPHIC CYCLE IN AN ARID CLIMATE[1]

BY CHARLES R. KEYES

(Presented before the Society December 29, 1911)

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[1] Received by the Secretary of the Society March 25, 1912.

Read by title under the caption "Geographic cycle in an arid climate: Should its development be by wind or water?" December 29, 1911.

Introductory

Since as ordinarily developed the scheme of the geographic cycle postulates an upraised land surface exposed to stream action and other erosive influences peculiar to a humid climate, its designation "normal scheme" is perhaps as fitting as any other term possibly could be. The normal plan, however, has had to be modified to meet two special conditions. On the one hand it has been adapted to a glacial climate, and on the other hand to an arid climate. A number of writers have recently described these variations, but always with the essentials of the normal scheme conspicuously before them.

In all of these considerations stream action or water alone is regarded as the prime agency of regional leveling and lowering. That there should be need of distinctive treatment to meet the requirements of those special conditions of climate where the snows of winter do not all vanish in summer, and for those conditions of aridity where all basins do not overflow and the surface drainage never reaches the sea, gives rise to the query whether this solution of the problem actually obviates the difficulties presented. There is at once invited a comparison of the relative efficiencies of the several erosive processes under diverse climatic conditions.

One of the immediate results of such comparison is the suggestion whether instead of attempting longer to fit closely the two so-called special cases to a humid-climate standard we could not with great advantage recognize a different standard for each of the three sets of climatic conditions. Would it not be indeed more logical to develop separate cyclic phases along lines indicated by the effects of the dominant erosional process for each particular climate?

There is now no question but that in the past we have been prone to attach far too much general importance to the special products of the geologic processes as they operate in a humid climate and with which we are most familiar. A direct consequence has been to overlook, often almost completely, the workings of other geologic processes the effects of which are really quite extensive. Perfect familiarity with provincial facts and provincial conditions readily leads to too broad generalization. That relative to which we are pleased to denominate normal climate appears to be no exception to the rule.

The deflative scheme of an arid geographic cycle here outlined appears to be abundantly supported by data recorded elsewhere. These facts are set forth mainly in three recently published papers. Without reiterating

here what they contain they may be pertinently considered in connection with the present discussion. Hence frequent reference is made directly to them. The present paper is the fourth of a closely connected series bearing especially on the arid regions of this country and the different phases of its eolative development. In the first account is described the remarkable rock-floors of the intermont plains of southwestern United States and northern Mexico.[2] A second article, dealing with deflation and the relative efficiencies of erosional processes under conditions of aridity, describes the salient relief features of an area to all appearances now undergoing rapid denudation.[3] The third memoir,[4] on mid-continental eolation, refers especially to a broad region where deposition of wind-blown materials is believed to be taking place on a large scale. This fourth statement is an argument for the development of the geographic features in an arid region chiefly through means of wind-scour rather than stream action.

Controlling erosional Agents under Diverse climatic Conditions

PREPARATION OF ROCK MATERIALS FOR EROSION

Since the effects of erosion are made most conspicuous through the removal of loose rock materials from the surface of the ground, the condition in which the degradational agencies find this rock-waste becomes a prime consideration. To the breaking down of rock-masses so largely influenced by climate the somewhat vague term "rock weathering" is applied. However, this term, familiar as it is, does not fully express the exact manner in which the transformation from the rock to rock-waste takes place.

The scheme of the normal geographic cycle premises moist-climate conditions, whereby the breaking down of the rocks at the surface is more largely chemical than mechanical. By implication at least the effect is regarded as a universal one, and little notice is taken of possible exceptions.

With greatest facility does chemical decay of rock-masses take place under conditions of heavy rainfall and warm climate. Yet long ago Von Richthofen[5] drew attention to the fact that in cold or in dry climates the rocks display few signs of chemical decay. Russell[6] further emphasized this feature when he said "that rock decay appears to be the

[2] Bull. Geol. Soc. America, vol. 19, 1908, pp. 63-92.
[3] Ibid., vol. 21, 1910, pp. 565-598.
[4] Ibid., vol. 22, 1911, pp. 687-714.
[5] Führer für Forschungsreisende, p. 100. Berlin, 1886.
[6] Bull. Geol. Soc. America, vol. 1, 1890, p. 134.

direct result of normally wet climatic conditions. In cold or arid regions the rocks are scarcely at all decayed." The production of rock-waste in desert lands through the process known as insolation is especially considered in another place.[7] At the surface of the ground it is shown to be very largely mechanical, hardly at all chemical in nature.

EFFECTIVENESS OF WATER ACTION IN MOIST CLIMATE

Those climatic conditions which tend to make of water action a most effective erosive agent, that in a humid land make it appear to be the sole process of general degradation, and that make it seem the only universal erosional activity are the very conditions which tend to obscure the effects of the erosional agencies which are most pronounced in a glacial climate and in an arid climate. Attempt to ascribe all erosion to stream action militates not so much against fact as it marks a distinctive period in the history of erosive thought. The composite effects in humid as well as in both arid and glacial climates remain to be properly analyzed. The factor of relative efficiencies of each has to be determined in every region.

If water be the dominant erosional power in a moist climate it does not necessarily follow that less water is the sole erosive force in either dry or glacial climates.

DOMINANCE OF WIND-SCOUR IN A DRY CLIMATE

Notwithstanding the fact that during the past decade the wind in the capacity of a potent agent of general erosion has come to be recognized more and more universally, there still lingers a certain reluctance to admit its effectiveness in specific cases or its high relative rank among the degradational processes. Even in instances in which the climatic conditions are such as almost to preclude water action, where the annual rainfall is so small as to be almost negligible, stream work is still given first place and wind work a very subordinate place.

That wind-scour in an arid land should be considered not only the dominant erosional activity, but under the peculiarly favorable conditions for its operations more potent and rapid in its effects than is water action in a normal, wet country is a quite recent deduction, but one which seems to be amply supported by many observations. More fully to appreciate the enormous extent of eolation, it is necessary only to peruse the later publications of certain astute observers who have actually lived in desert lands, although in this country this subject has not received the attention that it seems to deserve. Of these mention

[7] Bull. Geol. Soc. America, vol. 21, 1910, p. 569.

may be made of the work of Obruchew,[8] in central Siberia; of Walther,[9] in north Africa; of La Touche,[10] in the western Rajputana, in India; of Berg[11] and Ivchenko,[12] in the region about the Sea of Aral and on the Kirghiz steppes; of Passarge[13] and of Davis,[14] in the South African veldt; of Penck;[15] of Hundhausen,[16] in southern France; of Barron,[17] in eastern Egypt, and of Blackwelder,[18] in Wyoming.

Recent investigations in arid and semi-arid countries appear to demonstrate beyond all shadow of doubt that as a denuding, transportive, and depositional power the wind is not only fully competent to perform such work, but that it is comparable in every way to water action in a moist climate. As lately noted,[19] it is significant that most of the broad intermont plains of the Southwestern Desert, for instance, should be areas of rapid degradation instead of aggradation, as is shown by their remarkable rock-floors, that the little normal water action therein should be confined to the loftier mountains, and that the general plains surface should be so little affected by stream corrasion. General desert leveling and lowering must find for their chief sculpturing agency something other than stream action. All things considered, deflation, or wind-scour, in arid lands not only appears to be the principal erosional process, but water action surprisingly subordinate.

Under conditions of aridity the relative efficiencies of wind-scour and water action may be roughly measured by the circumstance that the total volume of rock-waste brought down by storm waters from a desert range in a year may be removed by the winds in a single day. What general erosion by means of water is in a wet climate, eolation is under conditions of arid climate.

EXTENT OF ICE SCORING IN A GLACIAL CLIMATE

Erosion by ice under conditions of a true glacial climate is probably not nearly so vigorous, widespread, or important as it has been thought to be. Further, it may be questioned whether in the case of great continental ice-fields there is sufficient motion except near the melting mar-

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[8] Verh. Imp. min. Gesellsch., St. Petersburg, vol. xxxiii, 1895, p. 260.
[9] Das Gesetz d. Wüstenbildung im Gagenwart u. Vorseit, 1900.
[10] Mem. Geol. Survey India, vol. xxxv, 1902, p. 10.
[11] Pédologie for 1902, p. 37.
[12] Ann. géol. min. Russie, vol. vii, pt. 1, 1904, p. 43.
[13] Zeitsch. d. deuts. geol. Gesellsch., vol. lvi, Protokol, 1904, p. 193.
[14] Bull. Geol. Soc. America, vol. 17, 1906, p. 435.
[15] American Journal of Science (4), vol. xix, 1905, p. 167.
[16] Globus, vol. cx, 1906, p. 46.
[17] Topography of Sinai, western portion, 1907, p. 17.
[18] Journal of Geology, vol. xvii, 1909, p. 429.
[19] Bull. Geol. Soc. America, vol. 21, 1910, p. 587.

gins to produce notable erosion effects. In the adaptation of the normal humid-climate scheme of the geographic cycle to that of a glacial climate the conditions postulated have not been those of a truly glacial climate, but those of a mountainous region where glaciers are present, which is a very different thing.

The marked distinction between mountain glaciers and continental glaciers, or inland-ice fields, is fundamental. This is especially emphasized by Hobbs.[20] Physiographically this distinction is far-reaching. The climate in the one case is not a glacial climate at all. The vigor and extent of ice scoring is more than commensurate with that which is displayed by the other. If anything, the absolute amount of abrasion is very much less in the last mentioned instance.

Continental glaciers seem to present conditions that are essentially desert conditions. The advancement of the ice-margin is probably more rapid through the constant outward drifting of the fine dry arctic snows than by any general motion of the ice itself. Recent observations in Greenland and Antarctica seem to leave little doubt of the existence of anticyclone areas over these inland-ice fields. Nansen[21] and Peary[22] in particular call attention to it in the north, while Shackleton[23] furnishes complete evidence of the existence of a South Polar anticyclone, which 20 years before had been advocated by Murray.[24] The drifting of the arctic snows is in all respects identical with the shifting of desert dusts and sands.

Formulated strictly according to boreal conditions and not on what is really a humid-climate basis, the commonly recognized scheme of a geographic cycle in a truly glacial climate needs radical revision. It may be that the glacial cycle could be with great advantage regarded as an arid cycle.

Relations of glacial and arid Erosion Conditions

In the paper read before the Geological Society in 1908[25] I incidentally compared the most striking effects of deflation in the desert with those of the winter blizzard on our northern prairies, where fine ice-dust and ice-sands take the place of mobile comminuted rock-waste. Were it possible to extend the blizzard a week or a month, or repeat it at short intervals for a longer period instead of a single day, the general plana-

[20] Characteristics of existing glaciers, 1911, p. 6.
[21] First Crossing of Greenland, vol. ii, 1890, p. 496.
[22] Geographical Journal, vol. x, 1898, p. 233.
[23] Heart of the Antarctic, vol. ii, 1910, p. 18.
[24] Geographical Journal, vol. iii, 1893, p. 1.
[25] Bull. Geol. Soc. America, vol. 21, 1910, p. 582.

tion effects might be soon rendered quite conspicuous and even the eolic erosion of the protruding rock hills might soon appear appreciable.

The association of the origin of the continental glaciers with eolic activities is no doubt more intimate and far-reaching in its physiographic bearing than might be at first glance supposed. During a greater part of the year arctic conditions are essentially desert conditions. The identity and nature of the rock weathering in the two climates has been already noted. The peculiar dry, powdery character of arctic snows are comparable in all respects to the fine dusts and sands of arid regions. In both instances the main effects of the wind on the loose materials are the same. Until the dry snows, through partial melting, consolidate into ice, they remain in the same condition as desert dusts before they become exposed to moisture. That the one should accumulate into vast continental ice-fields and the other into vast even-surfaced mantles of continental sedimentaries is a fact which strictly accords with the theoretic expectations of eolic action.

It appears that considerably over one-half of the land area of the globe is profoundly affected by eolic agencies. Murray[26] estimates that not less than one-fifth of the land surface is occupied by desert. At least another one-fifth is subject to greater or less accumulations of continental deposits of one sort or another in which wind-borne dusts form no inconsiderable part.[27] Perhaps another one-fifth is or was within recent geological times covered by snow-fields and physiographically is to be considered as truly desert as the Sahara.

Essential Features of Aridity

The peculiarities of an arid climate are generally described in terms of normally humid conditions. Contrasted with those of moist climate they have been lately especially characterized by Davis.[28] With particular reference to southwestern United States they have also been briefly noted by me.[29] To these papers further reference is subsequently made.

Contrasted Characteristics of Arid and Humid Initial Stages

SURFACE OFFERED TO SCULPTURING AGENCIES

Although the earth's crust with any structure, any form, and any altitude is postulated in the beginning for the normal or moist geographic cycle, the ideal and most complete cycle demands a recently upraised

[26] Science, n. s., vol. xvi, 1890, p. 106.
[27] Bull. Geol. Soc. America, vol. 22, 1911, p. 688.
[28] Journal of Geology, vol. xiii, 1905, p. 382.
[29] Bull. Geol. Soc. America, vol. 21, 1910, p. 568.

peneplain. Singularly enough, no large peneplain is known that still remains near the baselevel with respect to which it was worn down. On the hypothesis of regional lowering and leveling by stream action, great and even unsurmountable difficulties are at once met with in attempting to explain satisfactorily the larger relief features of deserts.

Under conditions of aridity and with wind-scour as the chief denuding power, there need be no recent regional uplifting in order to initiate the arid cycle of erosion. The affected area may be an old plain of peneplain-like aspect, or it may be a vast plains surface frequently interrupted by mountain ridges. Whether it could be ever an area occupied entirely by lofty mountains is very questionable. Altitude, however, is practically a negligible factor. The initial heights of some deserts were doubtless several thousands of feet above sealevel. In view of the possibility of desert-leveling, the flat-topped Bural-bas-tau and the associated plateau-like highlands in the Tian Shan range in Turkestan need reconsideration, as Davis well observes. Because of the strong possibility of its formation above baselevel in a region of inland drainage, Friederichsen[30] expresses objection to regarding it as a once low-lying peneplain, as urged both by Davis[31] and Huntington.[32] In southwestern United States, as represented by the remnantal plateau of the Mesa de Maya, the initial surface of the desert of that region must have been at least 8,000 to 10,000 feet above sealevel. The high South African deserts offer other examples.

On the other hand, desert lowering by the wind goes on below the level of normal peneplanation, not perhaps indefinitely below normal baselevel, provided the sea be kept out, as urged by Penck,[33] but some little distance below sealevel, until stopped by ground-water level, as apparently in the cases of the Death and Imperial valleys, in California. By deflation an arid cycle could be initiated on an old peneplain without any change in elevation.

The objections to ascribing a possible initiation of an arid cycle in a mountainous region I have already pointed out.[34]

ANTECEDENT RIVERS OF DESERT REGIONS

On the basis of the normal cycle, the drainage features, or rather the lack of them, in arid regions appear utterly inexplicable. Elevation of surface, which is so all important in the introduction of a new cycle in

[30] Petermann's Mitteilungen, vol. xlix, 1903, p. 136.
[31] Appalachia, vol. x, 1904, p. 277.
[32] Carnegie Institution Publications, No. 26, 1905, p. 157.
[33] American Journal of Science (4), vol. xix, 1905, p. 167.
[34] Bull. Geol. Soc. America, vol. 21, 1910, p. 589.

the moist climate, should in a dry climate have little direct influence if an eolic hypothesis be followed. This inference all observations seem to support.

The only evidences of antecedent drainage persisting against regional deformation and aridity are presented by the few very largest rivers which have their headwaters beyond arid limits and merely cross the desert on their way to the sea. They receive little or no augmentation to their waters within the area of the dry region. Entirely apart from the desert should these through-flowing streams be considered. The Rio Colorado, the Rio Grande, and the Rio Pecos in the arid country of southwestern United States, the Nile in northeastern Africa, and similar rivers really exert small influence in the general lowering of the lands through which they pass. In the cases of all other streams which in a humid climate would be classed as antecedent rivers all vestiges would be soon lost with the initiation of the arid cycle. Their disappearance would be not only because they had merely dried up, but for the reason that their entire valleys had blown away.

CONSEQUENT DRAINAGE FEATURES

Consequent drainage, which according to the humid-climate idea must prevail, is in several respects peculiar. It is doubtful whether it should be called consequent drainage at all. It is certainly not consequent drainage as it is understood in a moist-climate region. In a high-lying mountainous desert, such as is displayed in the province already noticed and in the Mexican tableland, whatever drainage there may be is mainly of the sheetflood order.[35] Even the streams coming down from the mountains tend to assume this character as soon as they reach the plains of the piedmont, as has been so graphically described by McGee.[36]

Certain peculiarities presented by these streams of the mountains are more fully discussed further on.

CENTRIPETAL DRAINAGE

The development of the present so-called consequent drainage of arid regions may not be necessarily, as has been urged, through the withering away of the lower reaches of streams belonging to a previous moist cycle. Neither may the independent centripetal systems belong to as many basins of initial deformation; that they should so belong is a necessary deduction of the moist-climate hypothesis. On the basis of an arid climate and a development of intermont basins through deflation instead

[35] Bull. Geol. Soc. America, vol. 19, 1908, p. 78.
[36] Bull. Geol. Soc. America, vol. 8, 1897, p. 87.

of through recent deformation, a very different explanation is made possible and probable.

If it be postulated that the high-lying surface of such a region as the northern Mexican tableland, already referred to, was at the beginning of the arid cycle a plain, an upraised peneplain possibly; that its major folding and faulting were quite ancient, mainly prior to peneplanation, and this seems highly probable;[37] that the present intermont plains represent the belts of weak rock undergoing vigorous deflation, as their rock-floors indicate, and that in consequence the mountain belts of resistant rock are now rapidly being brought into stronger and stronger relief, as all observation goes to show, centripetal drainage must be advancing and expanding as the mountain ranges become relatively higher. Such drainage systems are growing rather than withering.

MIGRATION OF BASINAL WASH

General misconception has long prevailed concerning the derivation and composition of the basin soils of arid regions. It is frequently stated that the smooth intermont plains are formed by the wash from their highland rims. The valleys of the Great Basin are notable examples. Concerning this region this view has been expressed by nearly every one who has written on the geology of this district during the past 30 years. The best statement of this impression is that by Russell.[38] Even so late as the past year an eminent geographer[39] has seriously emphasized this old notion. Enormous depths are attributed to the wash in the central parts of these intermont basins. Estimates of 3,000 to 4,000 feet are not infrequent. The contiguous mountain ranges are considered as "buried up to their shoulders." This conclusion is the direct result of applying the normal humid-climate principles to such regions. In accordance with the same principles the sides of each basin often to the mountain crests are regarded as initial slopes of local deformation, which lead the wash of the local sporadic rains toward the central depression, whose lowest point serves as the baselevel for the basin. With this interpretation the facts do not seem very well to agree. Expected verification of hypothesis in the field is not only not realized, but there is complete surprise at its manifest invalidity.

The arroyos, or drainage channels of the desert ranges, do not appear to be the notable wash carriers that they are sometimes thought to be. Plain with beveled rock-floor and mountain with bare rocky sides sharply

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[37] Proc. Iowa Acad. Sci., vol. xiii, 1908, p. 221.
[38] Geological Magazine, decade iii, vol. vi, 1889, p. 242.
[39] Harper's Magazine, vol. cxxiii, 1911, p. 54.

meet, and the great, thick, alluvial fans which one expects to encounter on every hand as the intermittent streams leave the highlands, are generally found to be singularly inconsequential. In place of huge fans miles in areal extent, hundreds of feet in thickness, and cubic miles in volume, which one is led to anticipate, their usual size and importance are almost ridiculously insignificant. Instead of vast extent and great bulk, examination shows that in a few days a steam-shovel and a train of cars could often remove every vestige down to bedrock.

The fact of the absence of thick wash accumulations in the central parts of many, if not of the majority, of intermont basins is strangely at variance with the assumption that the highland rims of bolson plains are eventually carried down by the rains and permanantly deposited in the lowest depressions. It appears that not only are many of these intermont plains not deeply covered by washed-in rock-waste, but that they are only veneered with soil.[40] The exceptionally dry Mojave Basin, in southeast California, seems to be a good example, if there be one, of an intermont plain so situated as to receive centrally the wash from a lofty rim because it is bounded on one side by the high wooded Sierra Nevada and on another side by the Sierra Madre. Moreover, the various low desert ranges within its boundaries are among the best instances known of "lost" or "buried" mountains. Yet nowhere in all of this desert is it more clearly shown that the basin floor is not deeply covered by rock-waste. Not only do the mountains and hills display the beveled edges of the strata beneath, but many square miles of its plains surface, even in its central part, are so thinly covered by soil that the underlying rocks are everywhere well exposed. The bedrock surface is, as I have elsewhere shown,[41] itself an even plain. This fact was long ago brought out in the geological descriptions of the region before its true significance was understood. Hershey[42] is especially explicit on this point, and more recently Baker[43] gives additional data of the same sort.

The records of deep drill-wells put down in various portions of arid America are often interpreted in support of the hypothesis that the intermont basins are deeply filled with rock-waste recently brought in by the rains. When critically examined, these drill-logs are found to be very misleading. In the majority of cases the great part of a drill-section is discovered to be in but slightly indurated Tertiary or Cretaceous or even Carboniferous deposits. Citing a specific instance: It was

[40] Bull. Geol. Soc. America, vol. 19, 1908, p. 63.
[41] Trans. American Inst. Mining Eng., vol. xl, 1909, p. 697.
[42] Univ. California Pub., Bull. Dept. Geol., vol. iii, 1902, p. 4.
[43] Ibid., vol. vi, 1911, p. 333.

claimed for the deep well at Albuquerque, New Mexico, that its 2,000 feet of depth were entirely in wash materials, whereas later, more careful and discriminating examination of the data clearly showed that scarcely 200 feet of the entire depth could be so considered. Similarly, certain deep drill-holes in southern Arizona are now known to have penetrated mainly tilted Tertiary beds instead of enormously thick wash deposits of quite recent date.

INITIAL RELIEF FEATURES UNDER ARIDITY

As already mentioned, there are two relief extremes on which an arid climate may be considered as imposed. They are a plain and a moderately mountainous surface. For obvious reasons a region of lofty mountains seems to be precluded. In the first instance the region is essentially a peneplain, although deprived of its streams. In the second case there is considerable diversity of relief, but no sharp, local contrasts such as are presented in a moist country in the beginning of a new cycle of erosion.

Contrasted Features of arid and moist Topographic Juvenility

CONDITIONS GENERALLY POSTULATED

As the early stage of the normal geographic cycle is commonly regarded, the relief is ordinarily and rapidly increased by the incision of consequent valleys from the trunk rivers that flow to the sea. In the early stage of the arid cycle the relief is considered, on the hypothesis of water action, to be slowly diminished by the removal of waste from the highlands and its deposition on the lower gentler slopes and on the basin beds of all of the separate centripetal drainage systems. In consequence all the local baselevels are thought to rise, and the areas of deposition are given a nearly level central floor of fine waste. Streams, floods, and lakes, then, are made the chief agencies in giving form to the aggraded basin floors, as well as to the dissected basin margins in the early stage of the cycle. In illustration the Great Basin is commonly pointed out. The winds are sometimes conceded to have some importance, but in the youthful stage wind-blown hollows are claimed to be not likely to be formed. For the normal headward growth of many subsequent streams it is explained that in the arid cycle such streams have smaller opportunity for development because all the belts of weak structure under the basin deposits are buried out of reach.

Clearly these statements are the result of deduction based on the consideration of conditions as they prevail in a moist climate rather than of generalization supported by long continued observations in a dry cli-

mate. One of the most serious objections to the development of desert landscapes by water action is the utter discordance between the necessary consequences of the moist-climate hypothesis and the facts actually observed.

YOUTHFUL ARID STAGE UNDER DEFLATION

On the basis of wind-scour action little that is ordinarily postulated for the early stage of the geographic cycle really obtains. The potency of water-work is found to be very greatly overestimated. The permanency of the deposits transported by the rains from the highland rims to the central lowlands of the intermont plains seems fanciful. The rising of the local baselevels appears to be poorly supported by facts. The development of drainage systems nowhere agrees with direct observation.

In the early stage of the arid cycle the relief seems to be rapidly increased by the hollowing out of broad flat-bottomed troughs or basins, laterally bordered by steep-sided, sharp-ridged mountain ranges. The air-streams accomplishing this work are hundreds of miles wide instead of a few hundreds of feet, as in the case of rivers; consequently the surface worked over is comparable to the channels of broad, shallow streams. Sharply incised topography so characteristic of humid lands is, therefore, impossible. General lowering is controlled partly by the proportions of weak and resistant rocks, partly by the extent and frequency of the faulting and other deformations of all previous time. Local conditions are sufficiently variable to enable the general lowering process to go on independently in the different basins, and the general leveling goes on also regardless of the relations of the denuded surface to sealevel. From the very beginning plains-forming is the most characteristic feature of desert-leveling. As the mountains become higher and higher normal water action increases on their sides, imparting to them something of the appearance of stream-graved surfaces. The relatively scant amounts of waste materials brought down and spread out from time to time at their bases are so rapidly removed by the winds that there is at any one time little actual accumulation. Rarely do sporadic cloudbursts carry notable quantities of the finer waste into the centers of the larger basins, there eventually to constitute thick deposits. Moving sand dunes are momentary phenomena. Permanent deposition of the finer waste goes on only beyond the boundaries of the desert in the bordering semi-arid belts or in the adjoining seas.

In the case of the youthful relief stage in a normally humid land its maturity is commonly regarded as approaching when dissection has gone on until the major drainage divides have lost some of their height and sharpness of outline and all elevations have begun to assume a notably

rounded aspect. In a dry climate, under ordinarily favorable conditions for deflation, the same general effects hold true, only in a somewhat different way. Of the positive relief features only the basinal rims can be properly considered. In place of the floor of each basin being intricately dissected by a ramifying system of more or less deep stream valleys, the effects produced in an arid country are as if all valleys of the more familiar lowlands of a humid land were everywhere filled. In order to picture more vividly the broader physiographic features of moist lands, this very procedure is indeed fancied.

With the ideal conception, facts ascertained for the northern Mexican tableland, for instance, seem fully to accord. Hypsometric differences of a mile are not unusual, and these are made possible by the great thicknesses of weak rocks brought by profound faulting into juxtaposition with extensive hard masses. In this region after the removal of the enormous thicknesses of soft materials from the broad belts of weak rocks the sharp ranges of hard mountain rock appear to be just beginning to have their summits notably worn off.

The effect of unlike initial tectonics on the arrangement of the local relief forms at successive stages is pointed out by Davis.[44] Contrasting a relief of coarse pattern with that of finer type, the region of central Asia is compared with that of western America. In the case of the first the vast even plains of eastern and western Turkestan are separated by a single broadly uplifted mountain belt; in the arid region of southwestern United States many short lofty ranges stud the general plains surface.

IDEAL TYPE OF EARLY ARID STAGE

The Great Basin, oftenest drawn on in illustration of the youthful stage of relief under influences of aridity, appears to represent a development of a considerable later type of desert topography. The facial expression of the northern Mexican tableland and of the desert regions of southern Arizona and of Sonora seem better to display what is to be expected of the features of this stage after exposure to the protracted arid conditions. With the deflative idea in mind, this region has received more attention than any other in this country. Moreover, its deformational periods are definitely fixed.

Throughout this broad area the alternation of hard and weak rock-belts is of the fine-pattern type. On this account features are presented which enable critical determinations to be made. In one respect the entire region is exceptionally peculiar; the resistant terranes are all segregated at the bottom of the stratigraphic column and the weak rocks

[44] Journal of Geology, vol. xiii, 1905, p. 384.

in great thickness at the top. The principal faulting and folding, on a gigantic scale, is quite ancient—long antedating the last great and recent epeirogenic upraising. With the initiation of the present arid cycle the whole area appears to have been a plains surface with small contrasts of relief—a peneplain to all intents and purposes. As this tract is now about to enter on its mature stage, the extremes of relief presented are between 5,000 and 6,000 feet. Almost ideal conditions and features of arid youth prevail.

CERTAIN CHARACTERISTIC DEFLATIVE FEATURES

The stage of arid youth presents certain physiographic features more perfectly than are shown at any other period of geographic development. These features it seems impossible to ascribe to an origin by water action. They are characteristics which point most conclusively to wind-scour as the sole erosive agent in dry climates. Nowhere outside of desert tracts are there known elevated plains of vast extent and even surface.[45] Only in the arid region do the mountains attain an isolation such as is not approached even by the ideal monadnock; most appropriately the Germans designate the effect the *Inselberglandschaft*.[46] The complete encirclement of mountain by plain finds no counterpart in moist countries.[47]

A noteworthy feature of desert ranges is a general absence of the foothills so inseparably associated with mountains that they are usually looked on as essential elements. Under conditions of aridity plain meets mountain sharply.[48] The beveled rock-floor of many intermont plains throughout the dry regions is explicable on no known activity of water action in such situations.[49] Existence of isolated plateau plains rising abruptly out of the general plains surface far from any sight of running water is an anomaly met with only in the desert.[50] Notable absence of distinct waterways in the desert basins, even when they have high gradients, bespeaks the utter impotency of water as an erosive agent in an arid climate.[51]

CERTAIN PECULIARITIES OF ARID YOUTH

The statement that rock-floors are of common occurrence in the intermont plains of southwestern United States has been recently chal-

[45] Bull. Geol. Soc. America, vol. 19, 1908, p. 63.
[46] Naturwiss. Wochenschr., n. s., vol. iii, 1904, p. 657.
[47] Journal of Geology, vol. xvi, 1908, p. 434.
[48] Bull. Geol. Soc. America, vol. 19, 1907, p. 572.
[49] Ibid., p. 573.
[50] Proc. Iowa Acad. Sci., vol. xiii, 1908, p. 221.
[51] American Geologist, vol. xxxiv, 1904, p. 160.

lenged, especially by Tolman.[52] This writer particularly emphasizes the conditions as they impress him around Tucson, in the Santa Cruz Valley, in Arizona, as affording conclusive proofs that the plains floor is not a beveled rock surface, but a vast accumulation of wash materials from the contiguous mountains. As is often the case, it appears that in this instance the illustration is not well chosen; that too much dependence has been placed on general impressions and not enough on critical observation. As I remember this locality it presents some unusually good examples of the planed rock-floor but slightly covered by soil. Bearing directly on this point, the neighborhood of the desert laboratory, near Tucson, is particularly instructive. In full corroboration of this statement McGee[53] notes that Tolman's "great ideal aprons of colluvial material were really so tenuous as to be entirely worn through in a three-inch deep path leading up to the Tucson Desert laboratory."

It is difficult to see, in view of the numerous recorded observations by many able investigators, why there should be any serious questioning of the existence of a rock-floor in bolsons unless it militate a time-tattered theory. Such planed basins are, to be sure, unlooked for features, and on a moist-climate hypothesis wholly impossible. There is, however, a constantly growing record of rock-floored bolsons. I have recently called attention to some of these features as they are presented in northern Mexico,[54] in Arizona,[55] in southern California,[56] and in Nevada.[57] McGee[58] describes similar phenomena in the Sonoran region of Mexico. In that remarkably dry tract, known as the Mojave Desert, Hershey[59] makes like observations, which Baker[60] quite lately fully corroborates. In extensive and systematic searches for underground water supplies for railway purposes conducted by me for roads already in operation and lines surveyed in the Southwest during the year 1902 and years following, it was long a constant surprise to find bedrock so thinly covered by soils. One of the most remarkable difficulties in railway construction on the smooth desert plains is the frequent encounter of bedrock in projected grade cuts of only a few feet.

Other arid regions display the rock-floored plains. I well remember so long ago as 1897, during some of the excursions of the Seventh Inter-

[52] Journal of Geology, vol. xvii, 1909, p. 136.
[53] Communication.
[54] American Journal of Science (4), vol. xv, 1903, p. 207.
[55] Bull. Geol. Soc. America, vol. 19, 1908, p. 63.
[56] Trans. American Inst. Mining Eng., vol. xl, 1909, p. 695.
[57] Bull. Geol. Soc. America, vol. 21, 1910, p. 543.
[58] Ibid., vol. 8, 1897, p. 87.
[59] Univ. California Pub., Bull. Dept. Geol., vol. iii, 1902, p. 4.
[60] Ibid., vol. vi, 1911, p. 363.

national Geologic Congress, with what utter astonishment I noted in so many localities on the steppes of southern Russia and on the Kirghiz steppes the rock-floor exposed in situations where water could not possibly have operated. Persian deserts left me with similar new impressions. When a little later I had occasion to visit the Saharan region, the bedrock peeping out from under the soils and sands of the Nubian and Lybian deserts convinced me then and there that the true explanation lay not in any phase of water action, for here the annual rainfall was less than one inch. The leveling and general lowering of arid tracts it seemed must be attributable mainly to eolic action, if not to the winds alone. Peneplanation without the aid of water became as real to me then as was peneplanation by means of water.

The alleged enormous depths of basinal wash as reported from time to time in deep well drillings have been already discussed. In all of these cases which I have personally investigated there manifestly have been mistaken for wash materials a great thickness of the little indurated Tertiary beds. In several such instances the Tertiary bedrocks were standing on end and the surface wash was but a few feet in thickness; in other cases the drill began in soft Cretaceous strata and there were reported nearly 2,000 feet of "wash." I do not doubt but there are in many localities wash deposits of considerable thicknesses; but it is also evident that before the usual data, and especially well-logs furnished by the average driller, are to be implicitly depended on they shall have to be critically examined anew in the light of recent determinations.

At a distance and on the hypothesis of normal water action we deductively should expect transferrence of the rock-waste from a basin-rim to central intermont depression. In the absence of direct stream connection with other and lower basins, we likewise should expect great accumulations of finer waste in the middle portions of the higher basins. On a basis of deflation thick basinal deposits are inexplicable; thin soil coverings are demanded. By wind the relief of an arid basin does not appear to be slowly diminished in the beginning by the removal of waste from the highlands and its deposition on the lower gentle slopes or on the basin-bed. In the case of the latter the presence of a rock-floor but thinly veneered by soils seems to be the strongest evidence that the basin itself is being rapidly lowered, not raised. The median line of a basin can hardly be regarded, therefore, a local baselevel of stream action.

In another place[61] I have shown that the geologic work of the ephemeral streams, sporadic sheetfloods, and transitory playas of arid plains

[61] Bull. Geol. Soc. America, vol. 19, 1908, p. 78.

is not comparable to the water action of moist climates, but that it is as idle as the shifting by the winds of the sands of the seashore. The finer rock-waste disturbed by these agencies is soon borne away by the winds as other soils of the desert. On the evaporation of the broad, thin sheet of storm waters producing playas the bottom muds curl up in thin leaves and are blown away. Playas and similar mud-flats of the arid basins must be considered as areas of rapid denudation and only temporary areas of relatively inconsequential aggradation.[62]

That subsequent streams in a strictly arid region have so small a chance for development does not appear to be due so much to the fact that the weak substructure of the intermont plains is deeply covered by waste as it is to the more obvious fact that there is not sufficient rainfall to form such streams.

Mature Stage of arid Relief

DEDUCTIVE COURSE OF DEVELOPMENT

In the modification of the normal geographic cycle to meet the new conditions imposed by an arid climate, several features are especially noteworthy. For the mature stage it is postulated that the continued erosion of the highlands and divides and the continued deposition in the basins produce a coalescence of local drainage systems, headwater erosion of consequent and subsequent streams, and aggradation of higher basins favoring this change; that a beginning is made of the confluence and integration of drainage lines which, when fully developed, characterize maturity; that when the drainage established across a former divide has a strong fall an impulse of revival and deeper erosion makes its way across the aggraded floor of the higher basin, which becomes dissected with bad-land expression; that this dissected floor then is smoothed at a lower level, and that in the last mentioned case the large areas of rock-floor are laid bare. Wind action is given a very subordinate place. In support of these distant deductions I have never found any evidence.

MATURE ARID FEATURES UNDER DEFLATION

The strongest contrast between the mature relief characteristics of normally moist lands and those of the desert under the influences of arid climate lies in the complete adjustment of consequent and subsequent streamways in the one case and the total absence in the other. The drainage integration which the moist country normally undergoes finds in arid lands no such intricate counterpart.

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[62] Bull. Geol. Soc. America, vol. 19, 1908, p. 84.

Of the larger relief features which distinguish maturity in a humid climate none is more conspicuous than a notable rounding of the sharp interstream tracts, hills, and divides and their rapid lowering. In an arid climate this same tendency is even more pronounced. The landscape effect, I take it, is perhaps nowhere so typically developed as in the Great Basin. With the vast planation effects displayed in the intermont areas of this region the sojourner at first is apt to get the erroneous impression so often described, that mountains are there buried up to their shoulders in their own debris. The idea long held that a mountainous tract of interior drainage may be reduced to a plain by the double process of wearing down of the ranges and the filling up of the basins seems not to be very well supported by the latest observations.

The unmistakable deflative features already noted in connection with the discussion of the relief of arid youth are even more pronounced in arid maturity. No known effects of rainfall and stream action can possibly produce the larger features of the relief expression which a region as extensive as the western American dry tract presents; the work accomplished is too prodigious, the time too infinitely long, the space affected too vast. Only by means of the wind under especially favorable circumstances could effects such as we see today be reasonably accomplished. Deflation seems the only explanation which is at all satisfactory.

DEVELOPMENT OF ORIGINAL DRAINAGE LINES IN DESERT REGIONS

The origin and growth of drainage lines, such as they are, in desert regions under conditions of general aridity is an aspect of erosion which has not, so far as I know, received the critical notice that it appears to deserve. This want of special attention to this single point has done more than anything else to mislead all who have traveled through the mountainous arid tract of America regarding the real ineffectiveness of stream action. Particularly deluding have been the impressions gained in such lands as those of our western country. In many mountainous belts of that region there is, indeed, an apparent approach to stream effects as they are known in humid climates. Upon this really quite restricted and peculiarly modified effect of normal water work has been based the usual scheme of the arid cycle.

In its broader relations stream action in the mountain belts of arid regions admits of an interpretation of origin wholly different from that commonly held. For example, in the arid region of the northern Mexican tableland it is perfectly conceivable—and I have already set forth the data in support of the idea[63]—that between the initiation of the present

[63] Journal of Geology, vol. xvii, 1909, p. 31.

arid cycle and the attainment of the mature stage into which that region is just about to enter the broad belts of weak Cretaceous rocks have been removed to depths of 5,000 feet and over. If at the beginning of the cycle of aridity the original surface were a plain, as there appear to be strong reasons[64] for believing, the present lofty mountain ranges must have differentially developed through the more rapid deflation of the belts of weak rock now forming the areas of intermont plains; for, as is well known, the stratigraphy of the region is remarkable in that the resistant rocks are mainly segregated in the lower part of the geologic column and the weak rocks are confined to the upper portion.

As the mountains rear their forms more and more above the general plains surface, while the latter is being gradually lowered through deflation, they finally become local rain-provokers of some small influence. During the period of arid youth the streams developed on the mountain slopes become slowly larger and larger and longer and longer until now, as the region is about to enter into its maturity, they attain their maximum size and efficiency. The mountains are now their loftiest, their sides are steepest, into them the intermont plains are encroaching deepest. The moisture gathering about them is greater in amount than at any time before or than will be afterwards. The mountain watercourses reach their greatest extension notwithstanding the fact that they carry relatively little water, are intermittent in character, and their lower reaches seldom pass beyond the foot of the ranges. Instead of being headwater remnants of extensive stream systems which have long since withered away under the influences of arid climate, as is a necessary consequence of the adapted normal cycle hypothesis, they must be regarded as original streams coming into being as the differential relief effects of regional deflation became more and more pronounced. With the advancement of physiographic maturity these streams must begin to wither, and as senile relief approaches they must with few exceptions undergo complete obliteration.

It is the custom to consider all water action upon the desert ranges as normal stream erosion in the process of dissecting recently upraised orographic blocks. This hypothesis seems to fall at once when it is considered that the major faulting of the mountain blocks is, as already stated, mainly very ancient, and not modern, as it has been so long assumed to be.

Certain effects of general deflation have greatly contributed to imparting to the mountain sides the infantile aspects of stream work. As recently suggested,[65] the locus of maximum lateral deflation in the desert

[64] Proc. Iowa Acad. Sci., vol. xiii, 1908, p. 221.

[65] Science, n. s., vol. xxix, 1909, p. 753.

ranges is their base, where plain sharply meets mountain without the intervention of foothills. The hard mountain rock is encroached upon at the level of the general plains surface as the sea gnaws away a line of its bordering cliffs, until, in many instances at least, the surface of the intermont plain extends into the mountain blocks distances of several miles. No more astonishing revelation was ever experienced by one who, on first entering the arid region of the West thoroughly believing in the prevailing theory of basin-range structure, was compelled to admit the facts so clearly presented that the sharp, straight line of meeting of mountain and plain was not a faultscarp at all, and that the major line of displacement was usually situated several miles out on the basin plain.[66]

If the deflative hypothesis of regional desert-leveling and lowering be accepted we have in the desert ranges a stream type hitherto unrecognized. The streams of this class have no history previous to the youthful stage of the present arid cycle; they have no prospect of relations with streams of any later cycle. Their birth, their span of life, their extinguishment are definitely circumscribed. They are the only existing streams we know of that do not have some sort of inherited relations with the waters of previous geographic cycles. They are the only streams the complete life histories of which may be distinctly traced at every stage. They are the only streams where origin is clearly fixed in time and sharply limited in space.

DURATION OF ARID MATURITY

The period of transition from arid youth to arid old age must be exceedingly brief. Compared with the corresponding stage of the normal moist-climate cycle it is almost ephemeral. So short is it that it can hardly be recognized as a distinct stage. Strongly supporting this conclusion are recent observations in New Mexico, Arizona, and Sonora.

As the broad belts of weak rocks, previously profoundly faulted, undergo through deflative influences the enormous denudation so manifest on every hand, the effect is not only rapidly to wear them down, but the narrower belts of resistant mountain rock are also encroached on as the latter are brought into stronger and stronger relief. In the case of the region just mentioned, where thicknesses of upward a mile have been removed, the hard masses of mountain rock have been eaten into at the base of the ranges for distances of 3 to 5 miles, and even more. There is thus left a lofty central ridge with precipitous slopes rising out of the plains as volcanic isles out of the sea.

Titles as the Organs, the Needles, the Castle Domes, and the Eagle Tails, locally applied to some of the desert ranges, well express the strik-

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[66] Science, n. s., vol. xxxiii, 1911, p. 466.

ing topographic aspects of the landscape. A generalized cross-section, based on the geologic structure of the Sierra de los Caballos, in New Mexico, indicates the common relations of relief and tectonics (figure 1). The perfect independence of the two are fully discussed in another

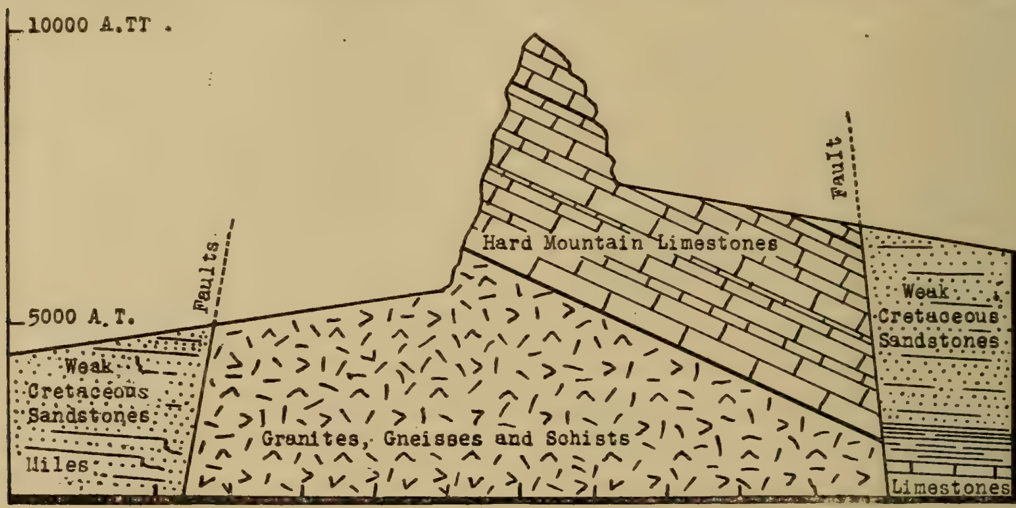

FIGURE 1.—*Passing of arid Youth: Rim of a Desert Basin*

place.[67] Another good example of the final mural ridge is that of the Palomas range, in southwestern Arizona, standing above the main mountain block more than 1,000 feet (figure 2).

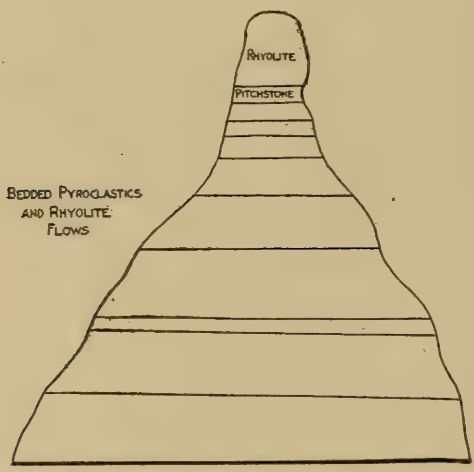

FIGURE 2.—*Approach of arid Maturity: Last of a Desert Range*

After the youthful stage here represented the upper remnantal portion of the mountain block is rapidly removed and reduced to a low, rounded mound projecting but slightly above the level of the general plains surface. Transformation from youth to old age is quick, decisive, complete. The apparently graded plains on either side of the old ridge gives it the aspect of a worn-down mountain buried to its shoulders in the waste of its own substances. In the case of the Caballos, already mentioned, the rock-floor of the plains is not confined merely to the higher parts of the piedmont slopes, as has been explained by Davis,[68] but extends for 30 miles across the intermont plain of the Jornada del Muerto to the next desert range to the east—the Sierra San Andreas.[69]

[67] Bull. Geol. Soc. America, vol. 21, 1910, p. 543.
[68] Journal of Geology, vol. xiii, 1905, p. 387.
[69] U. S. Geol. Survey Water Supply and Irrigation Papers, No. 123, 1905, p. 12.

The Great Basin appears to be a region long subjected to deflative influences that is passing through the mature stage.

Prevalence of old Age in Desert Regions

POSTULATED CHARACTERISTICS

According to the normal standard adapted to arid conditions, topographic old age begins to set in when a general reduction of the highlands gives rise to a notable decrease in rainfall and consequently stream action, and the process of drainage disintegration commences to predominate. Only at this time is wind-scour admitted to be at all effective.

TOPOGRAPHIC FEATURES OF OLD AGE UNDER DEFLATION

The drainage features of the latter part of the arid cycle may be entirely neglected. Topographic expression alone can be considered. Compared with that of maturity, there are scarcely any contrasts of relief. Desert lowering will be much slower because weak rocks will have been already largely removed. There is greater homogeneity of texture and hardness in the older rocks than in the more recently formed sediments, and consequently less opportunity for marked differential effects.

The prevailing relief expression in arid lands must necessarily be that of old age. The rapidity with which the several parts of an arid region passes through the different relief stages depends partly on the stratigraphic segregation of the hard as well as the soft rocks, partly on the character of the deformation, partly on the nature of the geotectonic pattern, and partly on the degree of aridity. Thus it is that under the same climatic conditions a certain provincial difference in the tectonics of the Mexican tableland, the Great Basin, and the Colorado plateau of Arizona permits the first to represent arid youth, the second arid maturity, and the third arid old age.

Baselevel of Eolian Erosion

The remarkable plains-forming tendency of deflation in dry regions is one of its main characteristics.[70] As already noted, the plain is the dominant relief feature from the very beginning of the arid geographic cycle; in a humid climate it only becomes notably developed at the very end. When Passarge[71] was conducting his investigations in the South African deserts he long had difficulty in understanding how it was possible under conditions of arid climate for general planation of vast tracts to go on without regard to sealevel, since the wind was thought to have no baselevel of erosion. So long as the waters of the sea are kept out, Penck[72] argued that deflation could go on indefinitely below sealevel.

[70] Popular Science Monthly, vol. lxxiv, 1909, p. 23.

[71] Zeitsch. d. deut. geol. Gesellsch., vol. lvi, Protokol, 1904, p. 191.

There appears to be, as recently shown,[73] a downward limit even to desert-leveling and eolic excavation. The ground-water level in each structurally inclosed basin must finally put a stop to wind-scour by keeping the surface above it moist, giving rise either to salinas or forming a basin into which sporadic storm waters find a long resting place.[74]

In illustration, many of the salinas of the dry region of western America might be enumerated. The lakes of Death and Imperial valleys, both below sealevel, in southern California; the basin of Lake Eyre, in Australia, the Sea of Aral, and other similar bodies of water in arid Asia are most notable. On a somewhat smaller scale are many of the lakelets of the Mexican tableland. Of these the Sandoval, the Hueco, the Casa Grande, and the Mapimi bolsons are best known.[75] The first of these[76] is the highest and driest bolson of the Mexican tableland within the boundaries of the United States. Its surface is 6,000 feet above the sea. Its center is occupied by a great chain of dry and bitter lakes. In all of its vast area and during a period of 400 years since the earliest occupation of the country by Europeans only two small springs of potable water were known within its confines. Recently it was inferred from the general character of the broad basin, its geologic structure, and the location of the two springs, that ground-water level at certain places must be very close to the surface. Proceeding on this hypothesis, several test wells were put down and the inferences found to be correct. At once there was excavated an area of several acres in extent for reservoir purposes. Now there stands a fine large body of soft water, the surface of which comes within a few feet of that of the surrounding plain. Around the lakelet a prosperous town has sprung up.

Depressions of the Saharan region appear to be downwardly arrested by ground-water level. Beadnell,[77] in describing the Kharga oasis, explains the presence of lake beds in the hollow by the uncovering of impervious clay strata and the consequent exposure of the surface-water sandstone with its artesian supplies. Long ago Lyons[78] called attention to similar phenomena in the Nile Valley, but the springs thus let loose were regarded by him as increasing local erosion.

Normal Water Action in Desert Regions

The derivation of the larger relief features of the arid regions through means of deflation does not necessarily preclude all normal sculpturing

[72] American Journal of Science (4), vol. xix, 1905, p. 167.
[73] Journal of Geology, vol. xvii, 1909, p. 661.
[74] American Journal of Science (4), vol. xvi, 1903, p. 377.
[75] Bull. Geol. Soc. America, vol. 19, 1908, p. 91.
[76] Journal of Geology, vol. xvi, 1908, p. 434.
[77] Geological Magazine, n. s., decade v, vol. vi, 1909, p. 476.
[78] Quart. Jour. Geol. Soc. London, vol. l, 1894, p. 531.

by water. The extent and character of water action are fully considered later. From the very nature of the special climatic conditions imposed by aridity, it follows that the erosional effects of the aqueous agencies must be reduced far below what is commonly expected of them. It is customary to regard desert landscapes as examples of normal water corrasion identical in origin with those of moist climates except that it is perhaps somewhat less rapid. In the present connection the importance of water action in matters of landscape details is not questioned; but the very secondary influence of stream corrasion in its broader operations is premised, and as a general erosional agency the dominance of wind-scour is recognized. Quantitative data on the relative efficiencies of the two processes are at hand and they are discussed at length in another place. Here the general results need be only briefly anticipated.

Water action in desert regions assumes three distinctive aspects: That produced by the through-flowing rivers, that of the intermittent torrential arroyos of the mountains, and that of the rare and brief sheet-floods. It is the second of these phases which mainly attracts the attention of the sojourner from less parched parts of the world. With a natural proneness to extend his moist-climate conceptions, the impression is at first gained that nowhere else is there so eloquent attest of energetic storm work as is presented on the desert ranges. Indeed the dominant characteristic of the arid sierras is notable ruggedness. It is apparently the same type of ruggedness which in moist-climate countries is by general consent ascribed to vigorous stream work on a recently upraised mountain tract.

Preconceived notions concerning general erosional effects under moist-climate conditions can not be *in toto* successfully transplanted to arid lands. The sharp meeting of plain and mountain without the intervention of foothills is certainly not a marked characteristic of water sculpturing in the mountains of moist climates. With much less amount of water involved, how may it be plausibly converted into a conspicuous feature in dry regions? The Castle Domes, Eagle Tails, Harquahalas, and Plomas ranges of southwestern Arizona are notable examples. In cliffs, picachos, minor and major crests they rise steeply out of the general plains surface. Yet the annual rainfall of this district is less than 3 inches. Instead of being distinctive forms produced solely by water action, there appear to be nowhere else so conspicuous illustrations of general undercutting of hard masses of mountain rock by the wind armed with sharp sands and aided by insolation. The locus of maximum lateral deflation action, as has been recently shown,[79] is at the level of the general

[79] Science, n. s., vol. xxix, 1909, p. 752.

plains surface, and this is constantly lowering. This feature is especially well shown in the Caballos and Plomas ranges (figures 1 and 2). On the basis of water action alone, the most inexplicable feature of desert configuration has always been how around the periphery of a mountain block a broad, perfect plain is produced, while in the middle a lofty, rugged mountain ridge exists. In the light of the changed angle at which the facial expression of the desert ranges is viewed, the alleged evidences of energetic storm work have to be critically examined anew. Bearing directly upon this point, it is not without great interest to note an expression of opinion by the late S. F. Emmons, than whom no one was probably more familiar with the arid regions of the West during a period covering more than 40 years. In the spring of 1903, when he was paying me a fortnight's visit at Socorro, he remarked that he was completely nonplussed that the desert mountain ranges should present such youthful topography on so huge a scale, and yet display so little evidence of adequate means with which to accomplish it; and he further stated, concerning the unsatisfactory character of all existing explanations, that in all his long experiences in the West this feature was the most puzzling of any which he had encountered or which had ever confronted geologists. At that time I had already followed the aqueous development of the relief features of the region to its necessary and wholly inadequate conclusions, and I had already begun to grasp the fundamental significance of the rock-floors of the arid intermont plains and the tremendous efficiency of wind-scour upon dry rock surfaces. Near the conclusion of the long discussions which this view aroused, Mr. Emmons dropped the statement that the conception was too new for him to grasp all at once, but that he believed that there was great merit in the wind explanation. It was, however, a full lenstrum before he told me one day that he had come to believe that the only adequate solution of the vexed problem would be through means of the wind and not water.

Recapitulation

The larger geographic features of deserts appear to find no adequate explanation of their origin by any known method of stream corrasion. For them wind-scour alone satisfactorily accounts. The necessary consequences of a strictly deflative hypothesis for the genesis of desert landscapes is everywhere amply supported by recently recorded observations. The geographic cycle in an arid climate is logically developed by considering wind action and not water action as the prime erosional process. For topographic detail important water action of normal character is not precluded.

FIGURE 1.—MORAINE ON NORTH-FLOWING STREAM: ZANE HILLS

FIGURE 2.—MORAINE OF FORMER LAKE SELBY GLACIER, KOBUK VALLEY

MORAINES IN NORTHWESTERN ALASKA

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GLACIATION IN NORTHWESTERN ALASKA

BY PHILIP S. SMITH[1]

(*Read before the Society December 28, 1911*)

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Introduction

The observations here recorded were made in the course of geologic investigations dealing primarily with the mineral resources of Alaska and were, therefore, incidental rather than the main objects of research. For this reason, as well as from the fact that the phenomena are highly complex, the present paper aims at little more than the presentation of some of the scattered observations that indicate the types of features recognized, leaving the coordination and the detailed working out of the Pleistocene-Recent history to the future.

Koyukuk-Kobuk Region

In the Koyukuk-Kobuk region shown in figure 1 the eenter of ice occupation in the past was the highlands to the north of the Kobuk, but the Zane Hills near the Koyukuk show evidences of past glaciation in the form of the valleys and in small moraines similar to that of figure 1, plate 34, which has a steep ice contact slope on the south or up-valley side. Too little is known of the real heart of the range north of the Kobuk to allow a full statement of its character, put it is probable that in the Kobuk drainage there are at present no large glaciers. In the past, however, glaciation of the valley type was pronounced, and has markedly modified the topography and left deposits characteristic

[1] Manuscript received by the Secretary of the Society March 5, 1912.
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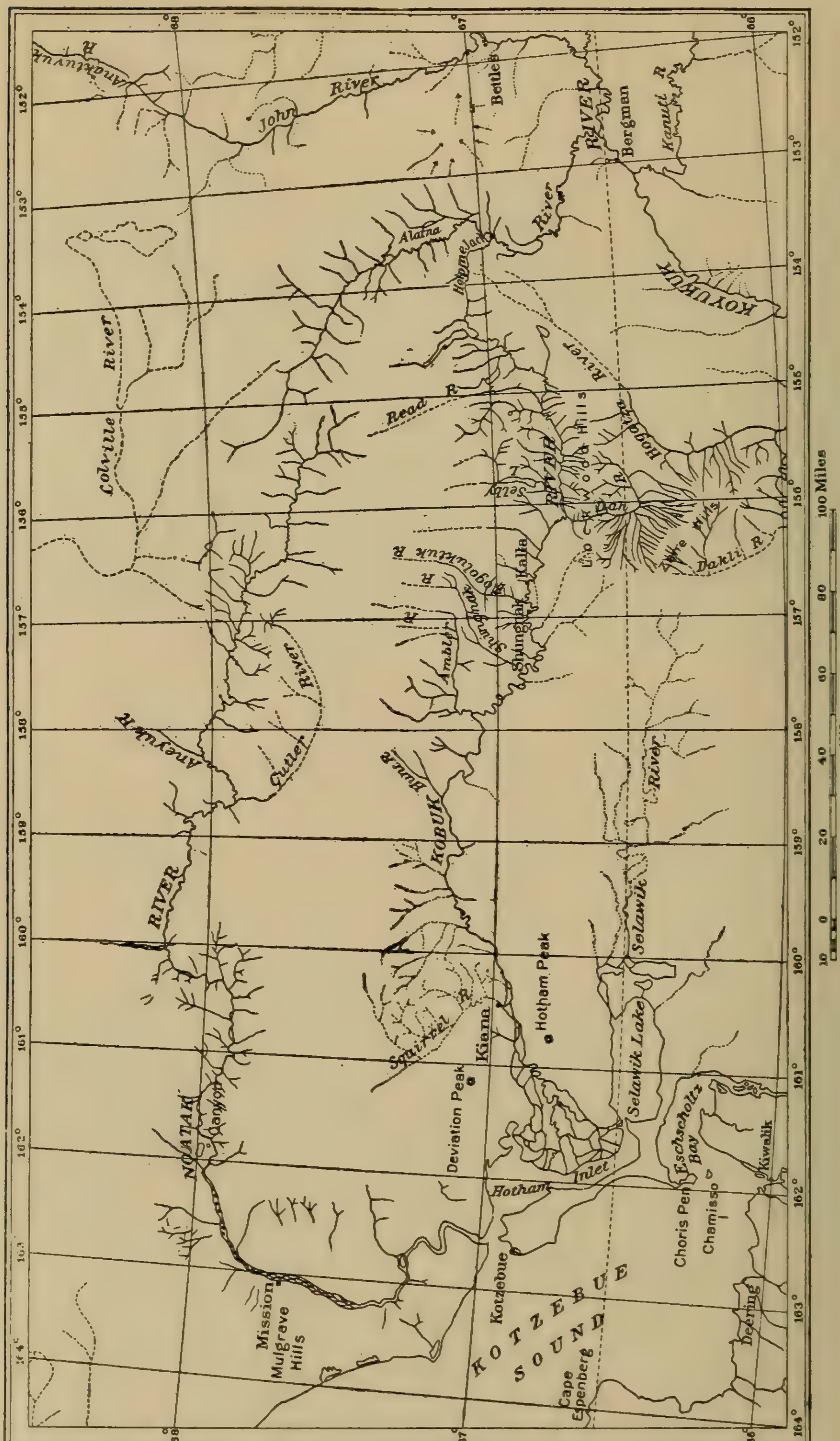

FIGURE 1.—*Explanatory Map of Part of northwestern Alaska*

Base furnished by U. S. Geological Survey

of glaciers. Cirques, U-shaped troughs, and overdeepened valley floors and oversteepened valley slopes bear witness to past glaciation. In the lowland of the Kobuk Valley are moraines in places over a hundred feet high which mark former fronts of valley glaciers tributary to the Kobuk (figure 2, plate 34). The relation of these moraines to the gravel filling of the Kobuk is not definitely proved, but they seem to rise above the general level with steep, north-facing slopes, and merge more or less uninterruptedly toward the south with the general surface of the lowland. These moraines are particularly prominent opposite the mouths of the larger valleys, as, for instance, those of the Ambler, Selby, Mauneluk, and Kogoluktuk.

It is believed that practically all the glacial ice that reached the main Kobuk Valley originated in the mountains to the north of the Kobuk, and, after flowing down the larger tributary valleys, on entering the Kobuk lowland expanded into lobes both east and west. Perhaps various lobes coalesced and a continuous Kobuk glacier was formed; but it seems as though the ice in the Kobuk Valley must have been dominantly stagnant rather than a vigorously eroding agent, and its effect was rather to obstruct earlier drainage than greatly to erode the previous topography.

As an instance of the obstruction of the glacial drainage may be instanced the drainage across the hills south of the Kobuk, east of Lake Selby. The details of the history of the changes have not been worked out, but it is believed that before the period of glaciation the Lockwood Hills formed the Koyukuk-Kobuk divide. With the advent of glaciation, however, the lobes of ice from the Endicott Mountains obstructed the westward drainage of the Kobuk and lakes back of the ice barriers were produced. For instance, the Lake Selby glacier is known to have formed a barrier in front of the mapped lake in the Kobuk lowland, and it is believed that earlier it extended across the valley so that a lake was formed upstream—that is, east of the barrier. As the lake rose, its surface at last reached the elevation of the lowest sag across the Lockwood range and spilled over. The channel thus formed was eroded rapidly until a narrow gorge was cut down to an elevation of 800 to 1,000 feet above sealevel. Evidence of the high level of the lake is shown by gravel terraces and irregular gravel deposits up to an elevation of nearly 1,000 feet above the Kobuk, or 1,400 feet above the sea. The narrowness of the gorge and the character and relation of the deposits point to the conclusion that the erosive agency was water rather than ice.

With the unblocking of westward drainage by the retreat of the Lake Selby glacier it appears that a lower gap was uncovered in the place now marked by Pah River. Downstream the large Ambler glacier still ob-

structed westward drainage, and it is by no means improbable that the Kogoluktuk and Mauneluk glaciers also crossed the Kobuk lowland and abutted on the hills to the south. It is possible that the Pah River pass was previously occupied by a south-flowing stream during the approach to maximum glaciation, but the records are so indistinct that they were not discovered. Suffice to say that the large terraces from 200 to 300 feet above the Kobuk seem directly referable to this stage.

With the further retreat of glaciation the Ambler obstruction was removed and a westward discharge permitted. It is difficult, however, to explain why the transverse south-flowing drainage byway of the Pah, having been established, was abandoned and the present northward course acquired. Possibly the cause is to be found in the unblocking of the western part of the Kobuk Valley by the retreat of the Ambler glacier; but the whole explanation is undoubtedly concerned with a number of correlated incidents. For instance, the glaciation of the north and east sides of the Zane Hills undoubtedly had an effect on the southward discharge. Thus, although it is believed that the Zane Hills glaciers never extended far from the front of the range, they probably fed a large amount of waste into the Hogatza lowland. This condition, with the diminution in the amount of water in the Kobuk and the unblocking of the former Kobuk Valley, may have so interacted that a reversal of drainage through capture was made possible.

Alatna River

In the Alatna River basin there is evidence not only of past glaciation, but even active glaciers were found in 1911. The existing glaciers are only 1 to 2 miles in length and are located in the high granite peaks to the west of the central part of the Alatna Valley. Figure 1, plate 35, shows the serrate ridges in the background and one of the glaciers. The elevation of the foot of the glacier is about 3,000 feet above the sea and the higher points are from 4,000 to 5,000 feet above the valley floor.

That the present glaciers are but the shrunken remnants of once more sizeable ones is evident from the topography and deposits at many places in the upper Alatna Valley. Topographically recognizable moraines are practically absent throughout the Alatna Valley, but resorted deposits containing large angular boulders, apparently ice-transported, are found at many places. In the central part of the valley a deposit of blue clay is formed of glacial rock flour. Ice-transported erratics and outwash gravel deposits have been found up to an elevation of 2,300 feet above the existing main stream. On the northern divide of the valley heading in the glaciers, at an elevation of over 2,500 feet above the stream,

FIGURE 1.—RIDGES AND GLACIER, ALATNA RIVER VALLEY

FIGURE 2.—OUTWASH PLAINS AND UPLAND LAKE, UPPER NOATAK VALLEY

ALATNA RIVER GLACIER AND OUTWASH PLAINS OF NOATAK VALLEY

is an angular block of granite more than 10 feet in shortest dimension, perched on exposed schist bedrock in such relations that it could only have been brought and deposited by a glacier heading in essentially the same region as the existing glaciers and of at least five times as large size.

Truncated spurs with triangular facets and steep slopes form the characteristic features in the upper Alatna Valley. In the central part of the Alatna Valley, Lake Takahoela marks a glacially overdeepened part of the old valley, and the ridge separating the lake from the river shows well-marked lea and stoss slopes developed on the roches mountonnées. The whole form of this part of the valley shows that it has been caused by a larger agent than running water, and has then been partly filled in so that the existing streams show patterns discordant with that of the valley.

Some ice from drainage basins now separated from the Alatna entered the latter valley during the maximum period of glaciation. Thus Mendenhall notes that the pass between the Keokuk and the Alatna was occupied by ice, and he states:

"Along Help-me-Jack Creek, in the Middle Alatna Valley, drainage changes have taken place that are best explained by glacial action. The direct topographic continuation of the Upper Help-me-Jack Creek Valley is eastward into the Alatna by the pass which leads to the latter stream in the vicinity of Rapid City, but Help-me-Jack Creek at present leaves this broad open way, turns to the south at right angles to its logical course, and reaches the Alatna at Beaver City. Such a course probably was originally a spillway for glacial waters, and in it Help-me-Jack Creek became intrenched while the more northerly outlet was still occupied by ice." [2]

Another pass to the east of the main Alatna River, near Lake Takahoela, served also as a spillway for both ice and water. This place is picturesquely known by the natives as Akabloouk, which means "daylight through the hills." It is a broadly open saddle, with an elevation of about 400 feet above the Alatna, and was formerly occupied by a drainage diverted to Malamute River, a tributary of the Alatna, when southward drainage was obstructed by the Help-me-Jack or Takahoela glaciers. The details, however, of the glacial and post-glacial history have not been worked out and many of the stages are obscure.

Noatak Basin

In the high hills at the head of the Noatak are many small glaciers similar in general character to those in the Alatna Valley. None of these

[2] W. C. Mendenhall: Professional Paper No. 10, U. S. Geol. Survey, p. 46.

was examined in detail, and as heavy fog masked the highest hills all the time we were in this region, those seen were probably only a few of those actually there. Although of no great size, the varied forms, from steep cliff glaciers to massive domes of snow and ice, add much to the picturesqueness of the scenery in the headwater region. Many of the unexplored side valleys tributary to the Noatak farther down stream seemed promising places to look for existing glaciers, but none was seen west of longitude 157.

Evidence of past glaciation and glacio-fluviatile conditions are abundant throughout the Noatak basin. In fact, the main source of danger in canoeing was due to the great boulders derived from the enormous outwash deposits of glacio-fluviatile origin that have been transected by the river. Boulders of all sizes, from hundreds of tons down, were found, some in the river and others just emerging from the gravel deposits. These large, glacially transported boulders seemed in the main to have been derived from the tributary valleys and not to have come from the valley of the main stream.

The deposits in which they occur were in the main of water-rounded and assorted material, with stratification usually more or less evident. The outwash deposits form broad gravel plains rising a hundred or more feet above the river. On the upland surface of these flats are lakes at many places but slightly incised below the general level. Figure 2, plate 35, shows a portion of the Noatak Valley where one of these upland lakes has nearly been drained by the lateral erosion of the stream when it was slightly above the level of the present Noatak, which appears to the right. The gravel bluffs here are about 100 feet high, but outwash deposits of well worn gravels near this place have been traced up to an elevation of about 900 feet above the river.

The canyon of the Noatak is another of the features that is probably in a measure connected with the glacial and glacio-fluviatile history of the region. The river at this place has abandoned a well opened out valley and has cut a narrow gorge 3 miles long from 500 to 700 feet deep across a former spur of hard rocks. Plate 36 shows the topography in the vicinity of the canyon. The former valley, now occupied by lakes, is in the background, with the present canyon partly visible in the foreground. A large stream joins the Noatak a short distance below the canyon, and the cause of the diversion is believed to have been the advance of a glacier down this valley and the blocking of the former course of the Noatak by ice deploying from this valley. The canyon is distinctly a feature carved by running water, and was not eroded by ice, so that the explanation of its origin assumes that the waters impounded

TOPOGRAPHY IN THE VICINITY OF THE NOATAK CANYON

behind the ice-barrier from the tributary valley escaped along the southern margin of the ice, and had so intrenched its course before the barrier was removed that it did not resume its course on the disappearance of the ice. Gravels up to an elevation of 700 feet above the Noatak River in the canyon have been observed on the hill slopes and bear witness to the former high level of the drainage.

Farther down the Noatak, near the point where it makes the big bend to the east, are deposits and topography that may have been formed by glacial activity. Northwest of this place is a broadly open gap not over 500 feet above the sea, that appears to have been formerly the direct course of the Noatak to the Arctic Ocean. Instead, however, of following this course, the river has abandoned this gravel-filled lowland, has swung southward and then eastward, and transected a range of hills 1,500 to 2,000 feet in elevation. On the slopes of the hills to an elevation of at least 700 feet above the river are gravel deposits. Near the bend before mentioned is distinct knob-and-kettle topography. The depressions are now occupied by small ponds from 100 to 200 feet above the Noatak.

The knob-and-kettle topography, the obstruction of direct westward drainage, the course of the Noatak across the topographic trend, and the presence of high gravels all point to a relatively recent change in topography, the cause of which is not known. Although unsupported by direct evidence, a possible working hypothesis to explain the diversion of the Noatak and the formation of the high levels is that glacial ice, occupying a part at least of the Arctic Ocean basin, obstructed the former westward discharge of the Noatak and caused outlets south and east of the ice-front to be utilized. According to this assumption, these outlets were uncovered only after lakes had been formed and their surface level raised many hundred feet. After this drainage had been established and had been intrenched, return to its former course may have been prevented by the glacial outwash deposits that would have accumulated in the old valley. It is also possible that the till reported by Hershey[3] near Kotzebue and the peculiar position and outline of Hotham Peninsula may have been formed at the eastern margin of the ice that obstructed the Noatak, rather than at the western front of a glacier from the Kobuk, for it seems almost certain that ice did not come down the Kobuk below the Kallareechuk.

It is realized that the above is little more than a speculation and requires much more corroborative evidence than is at hand before it can be

[3] O. H. Hershey: Journal of Geology, vol. 17, pp. 83-91.

seriously considered. If, however, past conditions are to be interpreted in the light of the present, it requires no great stretch of the imagination to picture the polar ice, which now bars this coast from nearly the middle of September to almost the first of July, having been proportionally as much more extensive in the past as the now vanished alpine glaciers undoubtedly were.

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STRATIGRAPHY OF THE COAL FIELDS OF NORTHERN CENTRAL NEW MEXICO[1]

BY WILLIS T. LEE

(Presented before the Society December 27, 1911)

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LOCATION OF AREAS EXAMINED

The areas in which the observations forming the basis of this paper were made lie in central and northern New Mexico, around the southern end of the main mass of the Rocky Mountains. The region includes the

[1] Manuscript received by the Secretary of the Society May 28, 1912.

This paper was presented under the title "Correlation of rocks in the isolated coal fields around the southern end of the Rocky Mountains in New Mexico."

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eastern part of the San Juan Basin, known also as the San Juan River region (107),[2] from the Colorado-New Mexico line southward to Cabezon, and the smaller fields to the southeast, namely, the Rio Puerco, Tijeras, Hagan, and Cerrillos coal fields. Observations were also made near Durango, in southwestern Colorado, in the type area of the Mesaverde formation. In addition to the observations made in these fields during the summer of 1911, some of the unpublished results previously obtained in the Raton coal field are used. The location of the area described is indicated on the accompanying sketch map, figure 1.

Purpose of Investigation

The purpose of this investigation was to determine the relation of the coal-bearing rocks east of the Rocky Mountains, in southern Colorado and northern New Mexico, to the coal-bearing rocks similarly located west of these mountains. The reason for undertaking it may be briefly stated as follows: Until recently the coal-bearing rocks in the Raton Mesa region east of the mountains were supposed to constitute a single formation, and this was correlated with the Laramie of the Denver Basin. However, a few years ago it was shown that the so-called Laramie of this region consists of two formations separated by an unconformity representing a time break of considerable magnitude, and that each formation was characterized by an extensive and well preserved flora. The flora of the lower formation, according to Doctor Knowlton, seems to prove that it is older than recognized Laramie, while that of the upper formation proves that this formation is post-Laramie in age.

West of the mountains, in the San Juan Basin, two coal-bearing formations occur in the upper part of the Cretaceous series. The younger one, at the top of the Cretaceous, has been correlated somewhat doubtfully with the Laramie, and the older one, or Mesaverde, is of Montana age and is separated from the "Laramie" by a thick formation of marine shale—the Lewis.

These two large areas of coal-bearing rocks—the Raton Mesa region and the San Juan River region—are situated on opposite sides of the Rocky Mountains, only 90 miles apart, but, unfortunately, none of the Cretaceous rocks extend continuously around the mountains to connect these two principal areas, so that continuous tracing of formations from one to the other is impossible. However, certain small isolated coal fields at the southern end of the main range of the mountains help to bridge

[2] The references to the publications cited in this paper are indicated by numerals, which correspond with those in "Bibliography and Notes" on pp. 659-686.

the gap. Furthermore, assuming, as is often done, that the first great uplift of the mountains occurred at the end of Cretaceous time, the post-Cretaceous unconformity found in the Raton Mesa region should be recognizable on the western slope and the post-Cretaceous formations east of the mountains should have recognizable counterparts on the western slope.

FIGURE 1.—*Map of Part of New Mexico, showing Location of Coal Fields*

The type of locality of the Mesaverde formation and the Lewis shale is in southwest Colorado, in the northern part of the San Juan Basin, where the Mesaverde is known to lie above shale that contains marine fossils of Pierre age, but relatively little has heretofore been known of the fossils contained in the Mesaverde, the Lewis, or the "Laramie" of this basin. In order, therefore, to correlate the formations east of the mountains, where good collections of both leaves and shells had been

made, with those west of the mountains, it was necessary to make collections from these three formations, as well as from the shale below the Mesaverde. This was done in all of the coal fields visited, and care was exercised to locate the collections as definitely as possible in measured sections.

Preliminary Statement of Results

The stratigraphic succession of the formations and their relation to each other were determined in each of the fields examined. The fossil plants collected have been examined by F. H. Knowlton and the fossil shells by T. W. Stanton. The correlations are based on the stratigraphic sequence of the formations, on lithologic resemblances, and on the fossils. Some of the propositions advocated in this paper may be regarded as essentially proved, others as fairly well sustained, while some are advanced only as working hypotheses.

Among the propositions that are regarded as essentially proved are:

(1) The thick shaale—the Mancos—below the principal coal-bearing formation in the southeastern part of the San Juan Basin is represented by a shale of similar character and essentially equivalent age in each of the smaller fields as far east as Galisteo. Although the top of this shale varies slightly in age from place to place, it represents a once continuous formation extending from the San Juan Basin eastward to some unknown distance beyond Galisteo.

(2) The principal coal-bearing rocks of the San Juan Basin—the Mesaverde formation—are represented by similar rocks in each of the smaller fields near the southern end of the Rocky Mountains, and although both the upper and the lower limits of the formation may vary somewhat in age from place to place, the coal-bearing rocks heretofore known as Laramie in these smaller fields are of essentially the same age as the Mesaverde of the San Juan Basin.

Among the propositions which may be regarded as probably true, although less well sustained than those noted above, are:

(1) The Mancos shale of the southeastern part of the San Juan Basin is essentially equivalent in age to the shale originally described as Mancos.

(2) The Mesaverde formation of the southeastern part of the San Juan Basin is lithologically similar to the original Mesaverde, but is thicker and may include rocks slightly younger than the typical Mesaverde.

(3) The base of the Mesaverde of the Rio Puerco field, as represented by the Punta de la Mesa sandstone, is several hundred feet lower in the

section than the base of that formation farther north. The Punta de la Mesa sandstone seems to be equivalent to a sandstone which in the vicinity of Cabezon occurs in the Mancos shale 500 feet or more below the base of the coal-bearing rocks—Mesaverde—of the San Juan Basin.

(4) The fossil plants from the so-called "Laramie" of the San Juan Basin indicate that this formation may be older than the Laramie of the Denver Basin.

(5) The flora of the coal-bearing rocks below the unconformity in the Raton field is similar to that of the Mesaverde, and tends to make that formation the time-equivalent of the Mesaverde. It has a less striking resemblance to the flora of the so-called "Laramie" of the San Juan Basin, which Doctor Knowlton regards as older than Laramie. On the other hand, the fauna of the shale immediately below the coal-bearing rocks of the Raton field is similar to that of the Lewis shale, and tends to correlate the older coal-bearing rocks with the "Laramie" of the San Juan Basin.

(6) Unconformities, representing erosion that probably took place after the close of the Cretaceous period, are found in all of the coal fields described in this paper. So far as is now known, this erosion originated in the post-Cretaceous uplift of the Rocky Mountains, but cut deeper in some places than in others, and persisted in some places longer than in others.[3]

Previous Investigations

In another section of this paper will be found a complete annotated list of the principal publications consulted during its preparation. Where practicable, the data that may be found useful in gaining a proper understanding of the geologic relations here discussed are enumerated. Among these publications there are many that give little new information, but are devoted principally to discussion or to reviews of papers previously published, and a few that have furnished practically all of the geologic information hitherto known. An attempt is made below to give a brief historic account of these investigations and place in chronologic order the principal contributions made toward an understanding of the geologic relations and age of the coals of central and western New Mexico and the rock formations with which they are associated. Most of those

[3] The results presented in this paper are so largely dependent on paleontology that more than ordinary credit should be given to Dr. T. W. Stanton, who identified the invertebrates and assisted the writer in other ways, and to Dr. F. H. Knowlton, who identified the fossil plants and placed at the writer's disposal a large volume of information not yet published, but which has a strong bearing on the problems of correlation.

relating to the Raton field have been omitted, for they will appear in another paper which is nearly completed.

Dr. A. Wislizenus (3) visited the gold fields south of Cerrillos in July, 1846, and although he makes no mention of coal in the Cerrillos field he observed the petrified wood that occurs in the Galisteo sandstone near the coal beds in this field, and states that coal occurs on the Rio Puerco in rocks supposed to be equivalent in age to those in the Cerrillos field. About two months later Lieutenant Abert (1) visited the Cerrillos field and found coal on one of the tributaries of Galisteo Creek. He also found coal on the Rio Puerco and collected fossils from rocks associated with the coal beds at Poblozon, a few miles north of San Ygnacio. According to J. W. Bailey, (2) these fossils proved the Cretaceous age of the coal-bearing rocks.

In 1849 James H. Simpson (4) visited the coal beds on the Rio Puerco at the eastern margin of the San Juan Basin northeast of Cabezon, and at several places farther west. Later, in 1853, Jules Marcou (6) reports coal "at Los Lunas and several other points on the Puerco," and compares the coal-bearing rocks with those of the Cerrillos field.

William P. Blake (9) examined the anthracite of this field in 1857, and also some coal in the Carboniferous formation near Santa Fe. He was inclined at this time to regard the Cerrillos anthracite as Carboniferous. A year later, in 1858, J. S. Newberry visited Santa Fe and secured samples of this anthracite, but did not visit the mine until the following year. He found coal beds near Fort Defiance, at the southern extremity of the San Juan Basin, in rocks which he referred to the Cretaceous, and others farther west, at Moqui, which he referred to the Jurassic. In 1859 he visited the Cerrillos coal field and examined both the anthracite and the "lignite" near Cerrillos and referred both to the Cretaceous. The full account of his investigation was not published until 1876, although a preliminary announcement of some of his conclusions was made in 1871.

In 1865 R. E. Owen (11) and E. T. Cox visited both the Cerrillos and the Rio Puerco coal fields. They referred the Cerrillos anthracite to the Carboniferous. In 1867 John L. Le Conte (13) visited the Cerrillos field and secured fossil leaves from the coal measures. From the evidence of these fossils he referred the coal beds to the Cretaceous, but placed them well down in the Cretaceous series. He regarded them as older than the "Marshall formation" or Laramie of the Denver basin. He also reports the occurrence of coal on the Rio Puerco west of Albuquerque. A year later he (15) reported the occurrence of coal near

Tijeras and referred again to the occurrence of coal in the Cerrillos and Rio Puerco fields, and near Tierra Amarilla in the San Juan Basin.

In 1869 Hayden (19), after a brief visit to the Cerrillos coal field, referred the coal beds to the Tertiary, basing his conclusion on the fossil plants which he found in abundance and which were later examined by Lesquereux. In 1870 Raymond (16) published a description of the coal beds of the Cerrillos and other coal fields, treating them from an economic standpoint. The following year Newberry (17) published a brief statement to the effect that the anthracite near Cerrillos is of Cretaceous age, and in 1872 Lesquereux (18) followed with descriptions of the fossil plants that had been collected from the Cerrillos coal measures and referred the beds containing them to the Tertiary, as Hayden had done three years before. A year later, 1873, (21) he correlated the Cerrillos coal beds with others which he regarded as Tertiary, notably with those at Raton, New Mexico (which have recently been shown to consist of two formations somewhat widely separated in time), and with the coal measures near Canyon City, Colorado, the age of which is still debatable. In the same article he refers to the coal measures in the Tijeras field, and also to coal near San Felipe—doubtless at the northern end of the Hagan field.

During the controversy over the geologic age of the "lignitic group" of Hayden, which raged in the early seventies, several more or less obscure references were made to the coal beds of northern New Mexico, but too little was known of them to bring them seriously into the controversy. Many of these are noted in the list of publications on pages 659-686, but need not be mentioned here, inasmuch as the character of the information contained is indicated by the notes accompanying the titles of the papers.

During the years 1871 to 1873, inclusive, certain explorations were made in regions west of the 100th meridian, including the areas described in this paper. Several geologists were connected with these explorations and published, in the Wheeler reports and elsewhere, many facts of interest regarding the coal measures of New Mexico. Loew (30) mentions the occurrence of "Cretaceous lignite beds" in the San Juan Basin near Nacimiento, and Cope (26) also published in 1874 a description of the coal measures exposed farther north in the same basin along the tributaries of the Chama River and elsewhere, in which he shows that marine rocks of Cretaceous age occur above the coal beds. These are evidently the Mesaverde coals of northwestern New Mexico, and the marine rocks above them constitute the Lewis shale of later writers.

Apparently Cope either did not find the "Laramie" of this region at this time or did not separate it from the overlying Tertiary rocks.

Again, in 1875, Loew (41) describes the "Cretaceous" coal beds near Nacimiento, and also those farther south on the Rio Puerco near San Ygnacio (42), as well as those in the Cerrillos and Tijeras coal fields. Analyses are given of the bituminous coal from Nacimiento and of the anthracite from Placer Mountain in the Cerrillos field. About the same time Stevenson presented a paper apparently not published until the following year, in which he mentions the Galisteo formation, and Cope (39) criticized the paper, stating that the Galisteo sandstone is Triassic in age (probably misled by the color of the rocks). The same error seems to have been made by others, for several contemporaneous writers refer to great numbers of petrified trees in the Trias of the Cerrillos region, whereas no rocks now admitted to be of Triassic age occur in this region, and all of the petrified wood known to the present writer is in the Galisteo sandstone. It does not appear from the literature that Cope actually visited the Cerrillos coal field at this time, as his route was from Santa Fe to the Sandia Mountains west of the field, but his descriptions are such as to indicate that he regarded the coal beds which he evidently knew lay east of his route as belonging in the Cretaceous, at least as high as number 4 (Pierre), inasmuch as his diagram (36) shows the occurrence of number 4 stratigraphically below the horizon where the coal is now known to occur. However, Stevenson (53) states that Cope referred the coal to Cretaceous number 3. In this same paper (36) Cope describes, in considerable detail, the coal measures west of Nacimiento Mountains. He referred the coal beds, which later writers have called Mesaverde, to Cretaceous number 3 (Niobrara), and found above them fossils which he regarded as indicative of Cretaceous number 4 (Pierre), which apparently is the Lewis shale, later described as occurring above the Mesaverde coal measures in this region. In another paper Cope (38) gives a graphic section of both Cretaceous and Tertiary formations, in which he indicates a covered area between his Cretaceous number 4 and the overlying Puerco formation.

In 1874 Cope (23) announced that he had found dinosaur bones which, in his opinion, proved that Hayden's "lignitic group" was Cretaceous in age, and Hayden (28) replied that he admitted the Cretaceous age of some of the coal beds of Utah, Arizona, and western New Mexico; also, Newberry asserted that he had proved the coal beds of New Mexico to be Cretaceous by the discovery of marine fossils above them (28 and 32), and that all of the plant-bearing coal beds in New Mexico are of

Cretaceous age, but Lesquereux (49) tried to strengthen his reference of the coal beds to the Tertiary by the evidence of the fossil plants.

In 1876 the delayed publication (44) of Newberry's account of his expedition with Macomb in 1859 appeared, and with it Meek's (43) description of the fossil shells collected by Newberry during that expedition. The coal beds of the Cerrillos field and those of the San Juan Basin are referred to "Middle Cretaceous," which, according to Newberry's classification, make them equivalent in time to the Niobrara. Cope (45) followed a year later with a paper, in which he referred these same coal beds, west of Nacimiento and Gallinas Mountains, to Cretaceous number 3, which, as just explained, is equivalent to the upper part of Newberry's "Middle Cretaceous." About a year later a striking example of the difference of opinion existing between the authorities of that time appeared when Lesquereux (49) included in his *Tertiary* flora plants from the coal measures of the Cerrillos field which Newberry (44) had previously referred to "Middle Cretaceous."

In 1877 Hayden's Atlas of Colorado was published and doubtless had great influence on such investigations as were later made in New Mexico. The mapping was extended southward over the area near Monero, described in this paper. By inspection it appears that the Colorado formation of this Atlas includes the shale both above and below the main coal beds which Newberry and Cope had referred to Cretaceous number 3. These are the coal beds which Schrader (100) later mapped as Mesaverde. The Atlas map shows the occurrence of a considerable development of so-called Fox Hills rocks in this region overlain by Wasatch. It is not clear what this "Fox Hills" is intended to represent, unless it be the very thin "Laramie" which occurs at Dulce and the massive sandstones of the post-"Laramie" formation, which is now known to lie unconformably on the "Laramie" in the vicinity of Dulce.

In 1878 and 1879 J. J. Stevenson examined the Cerrillos coal field and published (51) a preliminary account, in which he refers the coal-bearing rocks to the Laramie. At a time when such wide differences of opinion existed, as is indicated above, it would seem especially difficult to find the truth. Furthermore, Stevenson had worked east of the mountains in the Canyon City field and in the Raton Mesa region in beds which, by common consent, were called Laramie. Although some geologists had referred the Cerrillos coal beds to Cretaceous number 3 (Niobrara) and others had regarded them as younger than this, but still somewhat older than those of the Raton Mesa, Canyon City, and Denver fields, there seems to have been a general assumption at this time that the coal

beds of all these fields were of practically the same age, so that when those of the more northerly fields were called Laramie it was quite natural that Stevenson should extend the name to the Cerrillos field without presenting as clear evidence of age as could be desired. Thus, while Stevenson correlated the coal beds of the Cerrillos field with the so-called Laramie farther north, he held that the Laramie was Cretaceous. In other words, his Laramie was equivalent to the upper part of Hayden's Fox Hills group. In 1881 (52 and 53) the full account of Stevenson's investigation appeared, and although the coal beds are referred definitely to the Laramie, a step was taken toward their present reference to the Mesaverde when he reported (52, page 371) the occurrence of marine and brackish water fossils from "high up in the Laramie." It should be noted in passing that Stevenson's "Laramie" included not only the coal-bearing rocks, but many, if not all, of the younger rocks that other writers have described as Galisteo. The descriptions in his several papers on the Galisteo region, his maps of the region (54, number 77 (B), and number 78 (A)), and his cross-section (52 and 53, page 341, figure 49) leaeve no room for doubt that his "Laramie" includes the rocks of both the Mesaverde and the Galisteo formations of the present paper.

For several years after Stevenson's investigation little new information was gained concerning the coal measures of central and western New Mexico, but several more or less definite references to them are found in the literature. Cope, who was interested in the Tertiary vertebrates of northwestern New Mexico, makes mention of the underlying coal beds (55), which he refers, in part at least, to the Laramie. The coal beds of Gallinas Mountains are shown as occurring below "Fox Hills" (57), and the Puerco and Laramie are included under "post-Cretaceous," although Cope explains in the text that the Puerco belongs in the "Tertiary rather than the post-Cretaceous."

Little work was done on the coal-bearing rocks of New Mexico during the nineties, although Stevenson (69) visited the Cerrillos coal field again in 1896 and added a little to the information that he had already given. However, observations were being made by Cross, Spencer, and others in southwestern Colorado that were destined to have a notable influence on the investigations of the New Mexico coal-bearing rocks. In 1898 Spencer (73) announced that rocks of Benton, Niobrara, and Pierre age in southwestern Colorado are not divisible on lithologic grounds, and that massive sandstones occur higher in the section which might prove to contain equivalents of both Fox Hills and Laramie. This was followed a year later (75) by the La Plata folio, in which Cross names the coal-bearing rocks *Mesaverde,* the shale between them and the

Dakota *Mancos,* and the shale overlying them *Lewis.* The younger coal-bearing rocks, or "Laramie," occur in this region beyond the limits of the La Plata folio, thus making a section of the Cretaceous rocks which has become the standard for southwestern Colorado and northern New Mexico.

While the work just referred to was in progress in southwestern Colorado a series of independent investigations was being carried on by C. L. Herrick, then president of the University of New Mexico, and by others associated with him. They were not in close touch with other investigators, and although their work yielded much valuable information the results have not received the attention they deserve. In 1898 Herrick (72) published a preliminary paper, describing some of the Cretaceous rocks near Albuquerque, and two years later a more elaborate report on this region appeared, in which he, in collaboration with Johnson (77), described the stratified rocks extending from the Rio Puerco to the Cerrillos coal field. Much valuable information was given regarding the Cretaceous rocks below the coal beds, and the coal-bearing rocks were shown on fossil evidence to be of the same age in the Rio Puerco, Hagan, Tijeras, and Cerrillos coal fields and to be older than the Laramie. They were referred to the Fox Hills. This paper was followed in 1903 by one from D. W. Johnson (83), in which the geology of the Cerrillos region is described in detail. The coal measures were referred to the Fox Hills, and a somewhat extensive Pierre fauna was found in the shale below the coal; also a somewhat extensive Benton fauna was found near the bottom of this shale formation, but no fossils characteristic of the Niobrara were obtained. Evidence was found in some places of a commingling of Benton species with some that he regarded as characteristic of the Pierre.

The work of Herrick and Johnson was not extended to correlate in any way the rocks described by them with those described by Cross and others in southwestern Colorado, and their results, proving that the coal beds of central New Mexico are older than Laramie, seem not to have gained acceptance, for as late as 1907 Campbell (103), in writing of the coal beds of the Cerrillos and Hagan fields, states that "it is highly probable that they are Laramie."

In 1905 work was begun on the coal fields of New Mexico which has resulted in a series of publications leading up to our present knowledge of the coal fields. Schrader (100) traced the Mesaverde and "Laramie" formations from southwestern Colorado, where Cross had established their stratigraphic relations, eastward along the northern border of the San Juan Basin and southward to the Gallinas Mountains. Farther south the "Laramie" was not identified and the coal-bearing rocks

are described as "Upper Montana—relation to the Mesaverde unknown." This was followed in 1907 with a paper by Shaler (105), who traced the formations of southwestern Colorado around the western margin of the San Juan Basin.

In 1908 a paper was published by Shimer and Blodgett (109) which aids materially in correlating the coal measures of the Rio Puerco field with those of the San Juan Basin. These observers collected fossils at several localities between the two coal fields from the fossil-bearing zones that had been described by Herrick and Johnson as occurring in the shale below the coal beds of the Rio Puerco field.

A year later, 1909, Gardner (110) referred Schrader's "Upper Montana group" of the southeastern part of the San Juan Basin to the Mesaverde and found the Lewis shale and the "Laramie" coal beds higher in the section. This was followed by two papers from the same writer (116 and 117) in which these correlations were strengthened.

In 1905 the present writer began making observations in New Mexico, and in the following year (97) announced the discovery of bones of Triceratops in rocks younger than the coal measures near Engle, New Mexico, about 150 miles south of the area described in the present paper. These rocks have a conspicuous basal conglomerate that was later found to lie unconformably on the coal-bearing rocks.[4] In this and in a later paper (104) these rocks were provisionally correlated with the Galisteo sandstone of the Cerrillos coal field, and there in turn with the post-Laramie beds found elsewhere, which were at that time and still are by some geologists regarded as being of late Cretaceous age. The next step taken by the writer in this study was in 1908, when he discovered an unconformity announced in 1911 (111) in the Raton coal field of New Mexico. The coal-bearing rocks previously referred to the Laramie were found to be separated by this unconformity into two formations, the upper one of which was correlated on fossil evidence with the post-Laramie rocks of the Denver Basin, while the lower one contains a flora that is regarded as older than Laramie. In 1910 the writer, assisted by J. B. Mertie, spent the field season in tracing the coal-bearing formations around the Raton and Trinidad coal fields and in studying their relations to each other and to neighboring formations. A preliminary announcement of results was made (119), in which it was shown that the unconformity is readily traceable in all parts of these two fields. A large amount of evidence was collected bearing on the structural relations and the geologic age of these two coal-bearing formations, but the information is not yet

[4] Personal communication from Mr. Max W. Ball.

in form for publication. The greater part of the evidence of age is derived from fossil plants which are being studied by Dr. F. H. Knowlton. Although his study of them is by no means complete, it has progressed far enough to indicate that, in his opinion, the plants of the upper formation are undoubtedly of post-Laramie age, and that those of the lower formation are older than recognized Laramie.

During the summer of 1911 the writer carried on the investigations described in this paper in an attempt to correlate the formations of the Raton Mesa region with those of the coal fields south and west of the Rocky Mountains. A preliminary statement of results was given at the Washington meeting of the Geological Society of America, in which it was shown that the evidence derived from the study of stratigraphy, of fossil plants, and of fossil shells all agree in correlating the coal beds of the Cerrillos, Hagan, and Rio Puerco coal fields with the Mesaverde formation of the southeastern part of the San Juan Basin, and that the fossil plants associated with these coal beds are essentially the same as those found in the coal-bearing formation below the unconformity in the Raton Mesa region.

After the present paper was in type, but before it went to press, the writer, in company with T. W. Stanton, made some examinations in the Rio Puerco field and along the eastern margin of the San Juan Basin from Cabezon to Monero, principally for the purpose of determining the relations of the coal-bearing rocks in the southeastern part of the San Juan Basin to the typical Mesaverde in the northern part of this basin. The results of this work cannot be embodied in the present paper, but it may be briefly stated (1) that at least the lower part of the coal-bearing rocks at Cabezon is essentially equivalent to the Mesaverde as represented at Monero, which in turn is the undoubted equivalent of the original Mesaverde, and (2) that these same rocks seem to be equivalent in age to the middle and upper portions of the coal-bearing rocks in the Rio Puerco field: in other words, that the base of the Mesaverde in the Rio Puerco field, as represented by the Punta de la Mesa sandstone, is lower in the section by several hundred feet than the base farther north, and that these several hundred feet of sandstone and sandy shale are equivalent in age to the upper part of the Mancos near Cabezon.

Geologic Formations

THE TYPE SECTION

In 1899 Whitman Cross (75) published a section of the Cretaceous rocks that has become the standard for southwestern Colorado and western New Mexico. This section divides the Cretaceous into Dakota sand-

stone, Mancos shale, which is equivalent in age to Benton, Niobrara, and a part of Pierre; Mesaverde formation, Lewis shale, "Pictured Cliffs sandstone," and "Laramie" formation. The "Pictured Cliffs sandstone" may be regarded as the basal sandstone of the "Laramie" formation. The Animas formation, lying unconformably on the "Laramie," was correlated with the post-Laramie formations of the Denver Basin, which were then generally referred to the Cretaceous, but which have recently been referred to the Tertiary by G. B. Richardson (122).

This subdivision of the Cretaceous finds its latest expression in a section measured by J. H. Gardner, a few miles east of Durango, for use in a folio now in preparation. At the writer's solicitation Doctor Gardner has prepared the section for use in this paper as follows:

Section of Cretaceous Rocks measured on Florida River near Durango, Colorado (except the Wasatch, which was measured farther East)

(Data furnished by J. H. Gardner)

		Feet	In.	Feet	In.
Wasatch as determined by vertebrate remains. (Section measured on east side of Ignacio Quadrangle.)	Sandstone, massive ledges, coarse-grained, tan-colored, with thin beds of shale.....	80			
	Sandstone alternating with beds of shale...	70			
	Sandstone, massive, tan-colored............	20			
	Shale, variegated and thin sandstone.......	100			
	Sandstone, massive, coarse-grained, gray...	30			
	Shale, gray and drab......................	50			
	Sandstone, tan-colored, coarse-grained, with lenses of colored quartz and chert, average bird-egg in size........................	20			
	Shale, variegated with lenticular beds of brown and gray sandstone...............	400			
	Shale, variegated with benches of gray sandstone and thin ferruginous sandstone and sandy shale...........................	660			
	Sandstone, massive, soft, gray............	20			
	Shale, variegated.........................	50			
	Sandstone, massive, coarse-grained, dark-gray but locally purplish-brown..........	4			
	Shale, variegated with brown, reddish, gray and drab, with thin beds of brown and gray sandstone.........................	325			
	Shale, brownish and reddish, with lenses of conglomeratic sandstone; pebbles of colored quartz and chert chiefly............	85			
	Shale, yellowish and gray.................	50			
	Sandstone with small pebbles of quartz....	1			
	Shale, yellowish, drab and gray...........	60			
	Shale, tan-colored and reddish at the base, containing *Platanus reynoldsii* Newb. ? at the base..........................	250			
				2,275	

(Lithologic contrast. Unconformity not perceptible.)

		Feet	In.	Feet	In.
Animas formation	Sandstone, massive, tan-colored, micaceous with greenish igneous debris, alternating with yellowish shale	50			
	Shale, brown, drab, gray, and some reddish.	75			
	Sandstone, tan-colored, alternating with heavy beds of brown, greenish, drab, and yellowish shale, containing *Ficus* sp. ? and *Cornus* sp. 109 feet from the top and *Artocarpus lessigiana* (Lesq.) Kn.; and *Nyssa ? racemosa* ? Kn. 275 feet from the top	855			
	Sandstone, greenish-gray, with small igneous pebbles one-quarter inch in diameter in irregular zones	50			
	Shale and sandstone, greenish, locally conglomeratic	250			
	Shale, greenish	60			
	Sandstone, greenish and pink, with pebbles of schist and quartzite chiefly; pebbles 1 to 10 inches	20			
	Shale, greenish	15			
	Sandstone, greenish-gray, coarse, friable	10			
	Shale, greenish, and conglomeratic sandstone	20			
	Shale, carbonaceous	1			
	Shale, drab	2			
	Shale, carbonaceous	1			
	Shale, greenish, with silicified wood	81			
	Sandstone, gray and ferruginous, with sandstone concretions	10			
	Shale, dark red, bluish and drab	250			
	Sandstone, argillaceous, with andesite and other igneous pebbles and tuffs	20			
	Sandstone and shale with igneous matrix and pebbles	20			
	Shale, greenish and purple	50			
	Sandstone, yellowish	20			
	Shale, greenish, purple and bluish	20			
	Sandstone, massive, poorly consolidated, yellowish-white, and cross-bedded; contains *Ficus planicostata* Lesq. at the base	50			
	Sandstone, argillaceous, and some shale; igneous matrix	85			
	Tuff, coarse fragments of various composition	12			
	Shale, reddish, alternating with dark conglomerate and sedimentary debris	28			
	Tuff, reddish and pink, coarse-grained	7			

		Feet	In.	Feet	In.
Animas formation	Sandstone, brown, fine-grained, with round sandstone concretions	8			
	Shale, irregularly bedded, gray, friable	1	8		
	Sandstone, brown, coarse-grained, igneous matrix	4			
	Sandstone, yellowish and locally reddish	1			
	Sandstone, drab-colored weathers reddish, igneous matrix	15			
		——		2,091	8
	(Unconformity by erosion, and discordance of dip.)				
"Laramie"	Shale, yellowish, with sometimes a white sandstone near the top	50			
	Shale, drab-colored with some thin sandstone	100			
	Sandstone, massive, light colored	20			
	Shale, tan and gray	90			
	Sandstone, massive, soft, gray	12			
	Shale and soft sandstone containing at the base *Unio holmesianus* White; *Unio* sp.; *Corbicula* sp.; *Corbula subtrigonalis* M. & H.; *Tulotoma thompsoni* White; *Goniobasis* ? sp.; *Campeloma* ? sp. (U. S. G. S. locality No. 6063)	20			
	Sandstone, massive, rather hard, gray	20			
	Shale, brownish, and thin, soft sandstone	320			
	Sandstone, friable, gray		6		
	Sandstone, brown, containing *Brachyphyllum macrocarpum* Newb. and *Sequoia reichenbachi* (Gein.) Heer (U. S. G. S. locality No. 5462)	2			
	Sandstone, gray	15			
	Shale and some thin sandstone	30			
	Shale and thin sandstone, containing *Sequoia reichenbachi* (Gein.) Heer; *Carpites* sp.; *Juglans* sp.; *Salix* sp.? (U. S. G. S. locality No. 5463)	19			
	Coal bed	1			
	Shale and thin sandstone	10			
	Sandstone, soft in several beds	35			
	Shale	8			
	Coal bed "C"	3	1		
	Shale, carbonaceous	15			
	Coal bed		8		
	Shale, dark and drab	20			
	Sandstone, massive, gray with calcareous layer near base	50			
	Sandstone and shale, containing *Pholas* ? sp.; *Goniobasis* ? sp.; *Campeloma* ?				

		Feet	In.	Feet	In.
"Laramie"	sp.; *Viviparus* sp. (U. S. G. S. locality No. 6064) 43 feet above the base and fossil plants at the base....	150			
	Shale, containing both fresh water and brackish water invertebrates as follows: *Unio brachyopisthus* White; *Unio holmesianus* White; *Unio*, 2 undescribed (?) species; *Sphærium* sp.; *Martesia* ? sp.; *Viviparus* sp.; *Compeloma* ? sp.; *Tulotoma thompsoni* White; *Ostrea* sp.; *Corbicula* sp., related to *C. subelliptica* M. & H.; *Corbicula* sp.; *Corbula* sp.; *Melania* sp.; (U. S. G. S. locality Nos. 6071, 6072, and 6074), and fossil plants *Viburnum marginatum* Lesq. ? (U. S. G. S. locality No. 5454)..................	10			
	Coal bed "B"............................	12	2		
	Shale and thin sandstone, containing, 15 feet from the top, *Ostrea* sp.; *Anomia* sp.; *Modiola laticostata* White; *Corbula subtrigonalis* M. & H.? (U. S. G. S. locality No. 6065); 20 feet from the base are the fossil plants *Sequoia reichenbachi* (Gein.) Heer; *Quercus* sp., and at the base both shells and plants, *Anomia* sp.; *Corbula subtrigonalis* M. & H.?; *Cypris* ? sp.; *Melania* sp. (U. S. G. S. locality No. 6068), and *Brachyphyllum macrocarpum* Newb.; *Geinitzia formosa* Heer; *Sequoia reichenbachi* (Gein.) Heer (U. S. G. S. locality No. 5451).	50			
	Coal bed "A"............................	3			
	Shale, dark and drab.................	4			
		——		1,090	5

			Feet	In.	Feet	In.
"Laramie"	Pictured Cliffs Sandstone	Sandstone, gray, massive, top of "Pictured Cliffs sandstone," containing both invertebrates and plants: *Ostrea* sp.; *Inoceramus barabini* Mort.; *Cardium speciosum* M. & H.; *Tellina scitula* M. & H.; *Anomia* sp.; *Corbula subtrigonalis* M. & H.? (U. S. G. S. locality Nos. 6067, 6069, 6070), and *Geinitzia formosa* Heer? *Abietites dubius* Lesq. (U. S. G. S. locality Nos. 5446 and 5448)................	75			
		Shale, drab colored....................	15			
		Sandstone, massive, brownish..........	6			
		Shale, carbonaceous and coaly.........	3			
		Shale, drab colored....................	10			
		Sandstone, massive, gray..............	10			
		Sandstone, massive, gray with some alternating shale beds, bottom of "Pictured Cliffs sandstone," containing at the base *Ostrea* sp.; *Inoceramus* sp.; *Corbula* sp.; *Odontobasis* ? sp. (U. S. G. S. locality No. 6066)......	75			
		Transition sandy shale with beds of sandstone 6 inches to 1 foot thick....	200			
			——		394	
Lewis		Shale..................................	1,600		1,600	
Mesaverde		Sandstone, massive, light gray.........	10			
		Shale and sandstone..................	80			
		Coal bed................................		10		
		Sandstone and shale..................	170			
		Sandstone, massive, gray.............	20			
		Coal bed................................	2	7		
		Shale and sandstone..................	28			
		Coal bed................................	1	8		
		Shale.................................	12			
		Coal bed................................	2			
		Shale.................................	8			
		Coal bed................................	1	3		
		Shale and sandstone..................	12			
		Coal bed................................	4	6		
		Shale.................................	10			
		Coal streak sometimes present here.				
		Sandstone, massive, gray, containing *Ficus lanceolata* ? Heer.............	60			
			——		422	10

		Feet	In.	Feet	In.
Mancos	Shale with transitional beds of thin sandstone and shale at the top, containing *Gryphœa newberryi* Stanton, 60 feet above the base, 1,200 to 2,000 feet thick........	1,600±			
				1,600±	
Dakota and sandstones at base of Mancos	Sandstone, massive, gray, quartzose........	20			
	Shale, dark and gray, with local thin coal beds and some shaly sandstone..........	40			
	Sandstone, massive, gray, quartzose........	50			
	Shale and thin sandstone with local carbonaceous layers and thin coal beds......	100			
	Sandstone, massive, gray, quartzose.......	15			
				225	
	Total..............................			9,698	11

In order to correlate the formations described from central New Mexico with those of the Durango region, the writer made a somewhat hasty trip to Durango, where the Cretaceous formations are well exposed along the Animas River. Careful search was made for fossils in the Mesaverde, Lewis, and "Laramie." None were found in the Lewis, and the Mesaverde was found to be barren in many places, although a few shells and poorly preserved fossil leaves were found in it. Half a mile west of Twin Buttes, at the mouth of the gulch, entering Lightner Creek from the west, several fossil plants were found, but most of them are too poorly preserved to be specifically identified. They are *Equisetum* sp., *Sequoia reichenbachi* (Gein.) Heer, Fern, *Quercus* sp., *Quercus* n. sp., Palm, and *Ficus* sp. (United States Geological Survey, locality No. 6043). In this gulch, half a mile farther west, *Baculites anceps* var. *obtusus* Meek was found above the main coal beds. A single palm, *Geonomites* sp., very similar if not identical with a species common in the lowest coal formation of the Raton coal field, was found on the dump of an old mine in the Mesaverde coal, which opens in the gulch about 1 mile south of the Durango smelter, and on the dump of another mine in Horse Gulch, in the same coal measures, about half a mile east of Durango, *Ficus lanceolata* Heer and *Ficus* sp. were found. The fossil leaves seemed to be confined to very restricted zones closely associated with the coal. *Baculites anceps* var. *obtusus* Meek was found in the Mesaverde above the coal in several places near Durango. Such limited observations as were made in this region gave the impression that the Mesaverde is here essentially a marine formation. This observation seems to be verified by the work of other geologists. Fossils collected from this formation several years ago and identified by Doctor Stanton are as follows:

Mesaverde Fossils collected by Robert Forrester in southwestern Colorado

Anchura newberryi Meek	*Lucina* sp.
Acteon intercalaris Meek	*Lunatia* sp.
Baculites anceps val. *obtusus* Meek	*Odontobasis* sp.
" *compressus* Say	*Ostrea subtrigonalis* E. & S.
Callista deweyi M. & H.	*Pinna* sp.
Cardium bellulum Meek	*Panopœa* sp.
" *speciosum* M. & H.	*Placenticeras intercalare* M. & H.
Dentalium sp.	*Serpula* sp.
Fasciolaria sp.	*Sphæriola* sp.
Fusus sp.	*Turritella* sp.
Inoceramus barabini Morton	

The coal-bearing formation above the Lewis shale, near Durango, has somewhat generally been regarded as Laramie because of its stratigraphic position. These beds were found to be very fossiliferous in some places. Some of the fossils throw doubt on the Laramie age of the formation, but for the purposes of this paper it will be called "Laramie" in order to avoid introducing a new name. Doctor Gardner found several fossils in it and these are named in the foregoing section. The best collection obtained from it by the writer contains both plants and invertebrates. They were found in the west wall of Animas Canyon, half a mile south of Carbon Junction, about 200 feet above the lowest or principal bed of coal. A few fossil leaves were collected from lower horizons in the same formation near this locality by J. A. Taff in 1906, and by J. H. Gardner in 1909. In order to make the flora of this locality complete, these have been included in the following list and are marked thus (*):

Fossils collected on or near the Animas River, in the Durango Region, Colorado

(Plants, United States Geological Survey, Locality No. 6044)

Ficus speciosissima Ward	**Abietites dubius* Lesq.
Ficus trinervis Kn.	**Brachyphyllum macrocarpum* Newby.
Ficus lanceolata Heer	**Carpites* sp.
Ficus sp. (3-nerved, narrow)	**Geinitzia formosa* Heer
Quercus n. sp.	**Sequoia reichenbachi* (Gein.) Heer
Geonomites sp.	

(Shells, United States Geological Survey, Locality No. 7197)

Unio holmesianus White	*Tulotoma thompsoni* White?
" sp. related to *U. aldrichi* White	*Campeloma?* sp.
" sp.	*Viviparus* sp.
Neritina sp.	

In commenting on the age of these fossils, Doctor Knowlton says of the plants:

"Notwithstanding the fact that this collection is from rocks generally regarded as of Laramie age, there is not a single species in it that suggests the Laramie (of the Denver Basin). It is the same flora as that at Point of Rocks, Wyoming, and so far as I can see is of the same age, namely, Montana."

The shells collected by the writer are beautifully preserved, but they are of fresh-water species. Doctor Stanton says of them:

"I consider this a Laramie fauna. The unios are Lance types and the gastropods are of types that range from Mesaverde to Lance."

In addition to the fossils named above, a number of invertebrates have been collected from the "Laramie" of southwest Colorado by Robert Forrester (113, page 274) and J. A. Taff. Their collections have been joined with those made by the writer and by Doctor Gardner to make the following list, which includes all of the invertebrates known from the "Laramie" of southwest Colorado. The marine forms come from the Pictured Cliffs sandstone and the brackish water forms from the lower part of the shaly portion of the "Laramie" formation, although many of the latter occur above the principal coal bed. The fresh-water forms are from higher horizons:

Fossil Invertebrates of the "Laramie" Formation of southwest Colorado

Anomia sp. related to *A. micronema* Meek
Anomia sp.
Campeloma? sp.
Cardium speciosum M. & H.
Corbicula sp. related to *C. subelliptica* M. & H.
Corbicula occidentalis M. & H.
" sp.
Corbula undifera Meek
" *subtrigonalis* M. & H.
" sp.
Cypris? sp.
Goniobasis? sp.
Inoceramus barabini Morton
Inoceramus sp.
Martesia? sp.
Melania wyomingensis Meek?
" sp.
Modiola laticostata White
Neritina sp.
Ostrea sp.
Phosas? sp.
Sphærium sp.
Tellina scitula M. & H.
Tulotoma thompsoni White
Unio holmesianus White
" *brachyopisthus* White
" *verrucosiformis* Whitfield?
" sp. related to *U. aldrichi* White
" sp. undescribed, possibly 2 species
Viviparus sp.

The relation of the so-called Laramie to the younger formations exposed along the Animas River is not yet satisfactorily determined. Several hundred feet above the horizon of the fossils collected by the present writer there is a distinct change in lithology. A hard, massive, cliff-

making sandstone rests with uneven base on shale, and in the lower part of this sandstone was found a large bone, apparently a shoulder-blade. Only a small part of the bone was secured, and on examination it proved to be a Dinosaur bone, but no more definite identification was possible. This sandstone was not observed over a wide enough area to assert that it rests unconformably on the "Laramie," but the abrupt change in lithology and the uneven base of the sandstone suggest that it may be the lowest of the Tertiary formations. The presence in it of a Dinosaur and its position below the Animas formation, which has usually been regarded as equivalent in age to the Denver formation, suggests the possibility that the sandstone may be the time equivalent of the Arapahoe formation of the Denver Basin. This sandstone does not seem to be present on Florida River, where Doctor Gardner measured his section, unless the white sandstone at the top of the "Laramie" of that section, which is not always present, represents it.

The Cretaceous formations of the Durango region and their age relations are shown in tabular form below. The member and zone names used first in the Rio Puerco field have been added to this table, and also the Tertiary formation, so that the table expresses the age relations of all of the fields described in the following pages. With the exception of the Animas beds, there is no doubt of the Tertiary age of the rocks above the "Laramie" in the San Juan Basin. In the other fields described rocks of similar appearance and composition hold the same stratigraphic position, but their Tertiary age has not been proved. A massive sandstone, probably equivalent to the Pictured Cliffs sandstone member, was observed near Dulce and at the southern outcrop of the "Laramie" of the San Juan Basin northwest of Cabezon. The Punta de la Mesa sandstone member is the base of the Mesaverde in the Rio Puerco field. A similar sandstone occurs at the base of this formation in all the other fields described. The Cephalopod zone was first described in the Rio Puerco field, but was recognized also in the Hagan and Cerrillos fields. The Concretion (Septaria) zone was described first from the Rio Puerco field (77) as occurring "sometimes above and sometimes below" the Tres Hermanos sandstone. It seems to be of doubtful value as a horizon marker beyond the limits of the Rio Puerco field. The Tres Hermanos sandstone is typically developed in the Rio Puerco field, but is readily recognized in the Tijeras, Hagan, and Cerrillos fields, and is probably represented throughout the San Juan Basin. The Gastropod zone is best developed in the Rio Puerco field. It is sparingly fossiliferous in the Cerrillos and Hagan fields, and in the Tijeras field is repre-

sented by limestone concretions from which no fossils have yet been collected.

Table showing the Age Relations of the Cretaceous Formations of central and western New Mexico and southwestern Colorado

Systems	Groups	Formations	Zones and members
Tertiary		Galisteo of Cerrillos field and Tertiary formations of San Juan Basin	
Cretaceous	Montana	"Laramie"	
			"Pictured Cliffs sandstone" member
		Lewis shale	
		Mesaverde	
			Punta de la Mesa sandstone member*
	Colorado	Mancos shale	Cephalopod zone
			Concretion (Septaria) Zone
			Tres Hermanos sandstone member
			Gastropod zone
		Dakota sandstone	

DAKOTA SANDSTONE

A quartzose sandstone locally conglomeratic occurs at the base of the Cretaceous series in northern New Mexico. No fossils have been found

* The Punta de la Mesa sandstone at its type locality in the Rio Puerco field is here placed at the base of the Mesaverde, inasmuch as it is the lowest sandstone of the coal-bearing formation. However, it seems to be the age equivalent of a part of the Mancos shale as developed farther north.

in it, but because of its stratigraphic position and its lithologic character it is referred to the Dakota.

The so-called Dakota sandstone east of the Rocky Mountains in Colorado consists of two plates of sandstone separated by a thin shale. This shale, together with the underlying plate of sandstone, has been proved to be of Lower Cretaceous age, leaving only the upper plate in the Dakota (92 and 121). The writer has observed similar relations as far south as Las Vegas, New Mexico. However, no rocks of Lower Cretaceous age are known to exist west of the mountains unless the Morrison be of Lower Cretaceous age and the sandstone between the Morrison and the lowest shale of the Mancos constitutes the Dakota of this paper. This sandstone was found in all of the coal fields here described, and the few observations made on it are presented in the section of this paper devoted to the presentation of details of the areas examined.

MANCOS SHALE

The Mancos shale of central New Mexico includes the rocks, mainly shale, above the Dakota sandstone and below the basal sandstone of the Mesaverde. According to Schrader (100), Gardner (110 and 116), and others who have traced the Cretaceous formations from the Durango region eastward and southward through the San Juan River region into the area described in this paper, this formation is essentially equivalent to the Mancos of southwest Colorado (75). The present writer examined it at three localities in the San Juan Basin, namely, at Durango, in southwest Colorado; at Monero, and at Cabezon, in New Mexico. It is continuously exposed between Cabezon and the Rio Puerco field, but east of the Rio Puerco it disappears under a cover of Tertiary and Quaternary sand and gravel in the Rio Grande Valley, and nothing is known there of its occurrence and extent. East of the Rio Grande the surface is occupied by Paleozoic and older rocks of the Sandia Mountain block, on the eastern slope of which the Mancos and younger rock formations reappear, so little changed from their appearance on the Rio Puerco that even without the aid of fossils it would be difficult to believe that they were not once continuous between the two fields. But this similarity in the lithology and stratigraphic succession is confirmed by the fossils contained in them and leaves little room for doubt that the sea in which the Mancos shale was deposited extended from the San Juan Basin eastward over the Hagan-Cerrillos region.

When detailed observations are made on the Mancos of central and western New Mexico it will probably be subdivided into at least three formations, but for the purposes of this paper it will be preferable to

avoid the introduction of new names and to refer to the subdivisions as zones and members, using the names adopted by Herrick and Johnson (77) as follows:

The *Gastropod zone* occurs near the base of the Mancos in a shale formation 35 to 100 feet thick. In the shale are lenses and concretions of earthy limestone which contain great numbers of fossils in the Rio Puerco field. This shale is readily recognized in the other coal fields here described, but the fossils contained in it elsewhere are not so numerous as they are on the Rio Puerco. In the Cerrillos field it contains thin beds of coal near the base and in the Rio Puerco field carbonaceous shale. It seems probable that this may be the horizon of some of the so-called Dakota coal of the southwest.

Above this shale is a series of yellow sandstones about 150 feet thick on the Rio Puerco and thinner in some of the other fields. It thickens westward and thins toward the east. Herrick and Johnson called it the *Tres Hermanos sandstone,* and this name may be used to designate the zone of yellow sandstone that occurs near the base of the Mancos in all of the fields described in central New Mexico west of the mountains. It seems to represent some of the sandstones of Benton age which are coal-bearing in western New Mexico.

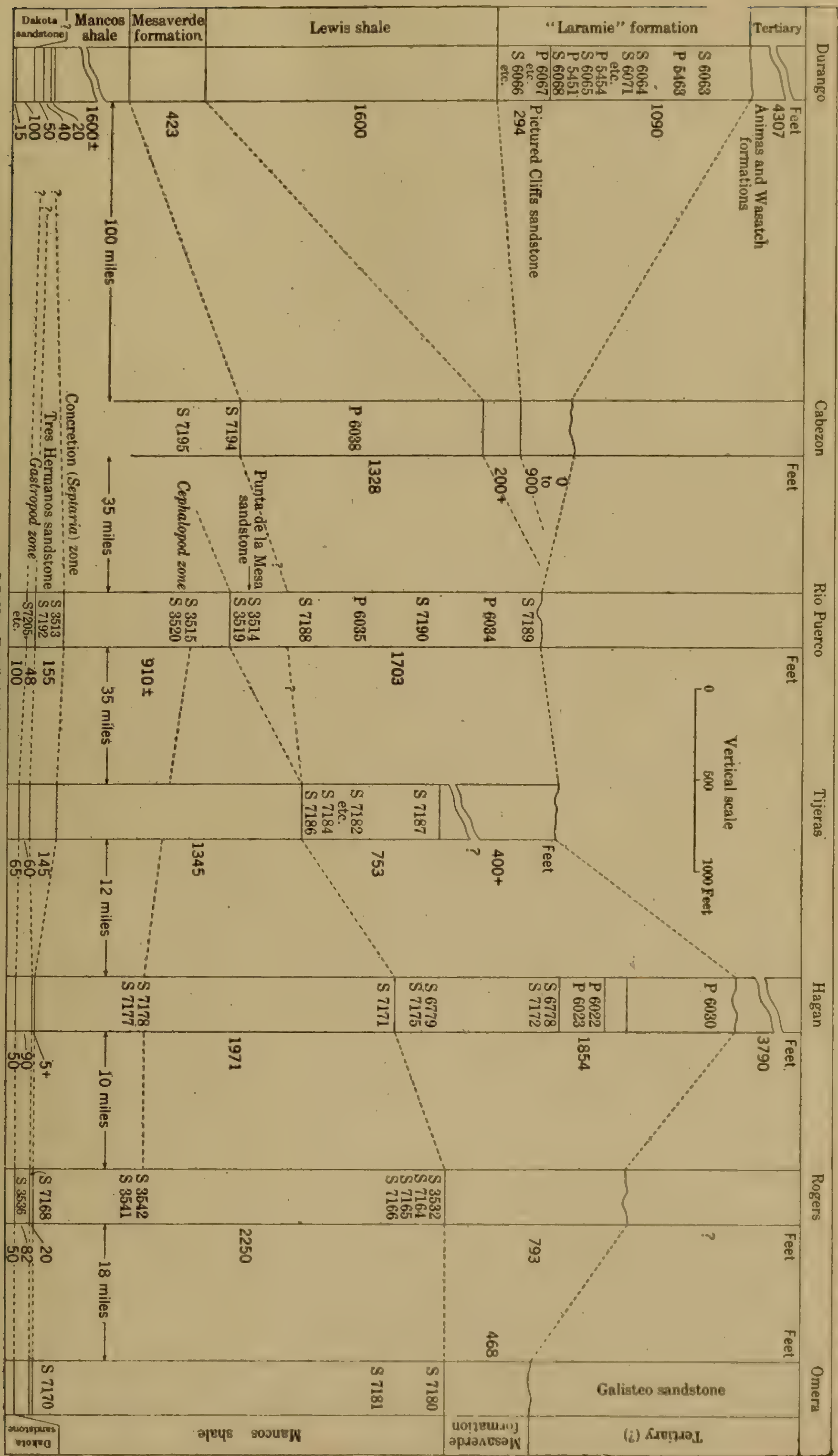
The principal part of the Mancos shale occurs above the Tres Harmanos sandstone. It is a more or less homogeneous shale 1,200 to 2,000 feet thick in the Durango region, about 1,000 feet thick in the Rio Puerco field, and considerably thicker in the fields east of the Rio Grande. It is not divisible lithologically into Benton, Niobrara, and Pierre, but the fossils contained in it prove that it contains time equivalents of the Benton, probably the Niobrara, and some of the Pierre. Two zones of fossiliferous concretions have been described within this shale in the Rio Puerco field, but it is not known how definitely they can be recognized in other fields and their value as horizon markers is doubtful. A *Concretion* (*Septaria*) *zone* occurs in the Rio Puerco field (77) in close association with the Tres Hermanos sandstone. This zone was recognized by Shimer and Blodgett (109) in several places between the Rio Puerco field and Cabezon, but its occurrence east of the Rio Grande is doubtful. A *Cephalopod zone* (77) occurs in the Rio Puerco field 600 feet or more stratigraphically above the Concretion zone. It is characterized by great numbers of limestone concretions containing cephalopods and other shells. This zone seems to be fairly persistent throughout the Rio Puerco coal field and to be recognizable in many places between this field and Cabezon. East of the Rio Grande a zone of concretions containing the fauna of the Cephalopod zone occurs about 700 feet above the base of the Mancos

shale and seems to be the time equivalent of the Cephalopod zone of the Rio Puerco field. The fauna of the Cephalopod zone occurs in some of the concretions formerly supposed to indicate the Concretion (Septaria) zone, and there seems to be confusion regarding the latter zone. It is probable that some of the two invertebrates described from the latter belong to the Cephalopod zone.

The determination of the place at which the top of the Mancos should be drawn in the time scale involves some difficult questions. In its type area in southwestern Colorado this shale includes at its top rocks of Pierre age (73). The shale below the coal-bearing rocks in the Cerrillos field seems to have the same range, but in the Rio Puerco region fossils indicative of Benton age occur near the top of the shale. According to Mr. Schrader and Doctor Gardner, previously quoted, the Mancos shale was traced from the Durango region east and south to Cabezon. But as has formerly been stated, the upper part becomes sandy farther south, and in the Rio Puerco field is not readily separated from the overlying Mesaverde.

East of the Rio Grande the Mancos shale is much thicker than it is in the Rio Puerco field. At Hagan it has a measured thickness of 2,116 feet. A characteristic Benton fauna occurs in the lower 700 feet or more of this shale, but the upper part contains fossils that range upward through the Mesaverde. The few fossils found at the top of the Mancos near Hagan were close to the basal sandstone of the Mesaverde, but in the Cerillos field this fauna seems to extend downward 200 feet or more into the shale. In this latter field the Mancos has a measured thickness of 2,402 feet. The lower part of it is clearly of Benton age and some of the rocks are probably of Niobrara age. The upper part contains a great number of fossils that belong in the fauna of the Lower Montana. This occurrence of Montana fossils below the Mesaverde necessitates the reference of the rocks containing them to a horizon near the base of the Pierre. In order to bring out more clearly the fact that the Mancos shale on the Rio Puerco is faunally similar to only the lower part of this shale farther east, the fossils from the lower part are listed separately from those of the upper part, although all belong to the same formation.

The fossil invertebrates of the Mancos are included with those of the Mesaverde and the Lewis in the following table, and their general distribution is indicated therein. Unfortunately, a great many of the species have never been described, and their names as published in the table are of little value in correlation. However, in a report on the fossils



S 7189 = Fossil shells in U. S. G. S. collections
P 6034 = Fossil plants in U. S. G. S. collections

FIGURE 2.—*Correlation of Formations in New Mexico Coal Fields*

collected by the writer, T. W. Stanton makes the following statement, covering both the Mancos and the Mesaverde fauna:

"The distribution of the faunas agrees with the field determination that the coal-bearing rocks of the Cerrillos, Hagan, Tijeras, and Rio Puerco fields [also those of the Cabezon region] all belong to one formation. In the Tijeras and Rio Puerco fields the marine fauna associated with the coal occurs in rocks overlying part of the coal beds as well as immediately beneath them [as described by Mr. Lee, who collected the fossils]. This fauna is closely related to the Cretaceous faunas of the Gulf and Atlantic borders and is especially related to the fauna which occurs a short distance beneath the coal at San Carlos near the Rio Grande in western Texas. It apparently does not extend far northward, the most northern point at which it has been found being in the neighborhood of Cabezon. It is, of course, true that there are some similar and perhaps a few identical species in the Montana group faunas of Colorado and more northern areas, but the general association of forms and most of the species are entirely different. Its horizon is that of the lower part of the Montana group not far above the horizon of the Austin and the Niobrara, and hence apparently somewhat lower than the upper part of the Mancos as developed in southwestern Colorado. It is my judgment, therefore, that the base of the coal-bearing rocks in the central New Mexican fields mentioned is lower, perhaps by several hundred feet, than the base of the Mesaverde in the neighborhood of Durango, Colorado. It is worthy of note that Mr. Lee's collections show a good development of the Benton fauna in the beds underlying those containing the fauna associated with the coal, and this Benton fauna is, with some additions, essentially the same that occurs in the lower 400 feet of the Mancos shale in its type area, and also in the Benton east of the mountains in Colorado."

MESAVERDE FORMATION

The Mesaverde consists principally of sandstone, shale, and coal. It is 423 feet thick near Durango, Colorado, and about the same at Monero, New Mexico, but is very much thicker farther south. Most of the sandstone is yellow and occurs in beds, some of which are massive and thick, alternating with shale. In some places the sandstone is more or less lenticular and contains irregular masses of impure limestone with great numbers of marine invertebrates. Some of the shale also contains marine fossils. These rocks of marine origin alternate with those containing beds of coal and fossil plants.

Fossils were collected from the Mesaverde at many localities. Those collected where the sections were measured are denoted by the lot numbers, which identify them in the collections of the United States Geological Survey, and the same numbers are placed in the generalized sections, figure 2, to mark the horizons from which they came. The localities where they were collected are also indicated by the same numbers on the accompanying map. Those collected at a distance from the

Table of Distribution of Cretaceous Invertebrates from southern Colorado and northern New Mexico

Identified by T. W. Stanton

	Mancos						Mesaverde				Lewis	Pierre and Trinidad
	Lower		Upper									
	Rio Puerco	Hagan and Cerrillos	Durango	Cabezon	Rio Puerco [5]	Cerrillos	Durango	Cabezon	Rio Puerco	Hagan	Dulce	Raton
	1	2	3	4	5	6	7	8	9	10	11	12
Actæon intercalaris Meek	...	...	...	...	...	...	×	...	...	...	...	...
Actæon sp. (several undescribed species)	×	×	...	×	...	?	...	×	?	×	×	...
Acanthoceras ? sp.	×	...	...	...	...	...	...	...	...	...	...	...
Anatina sp.	...	×	...	...	...	×	...	...	...	...	...	...
Anchura fusiformis White non Meek.	×	...	...	...	...	...	...	...	...	...	...	...
Anchura newberryi Meek	...	...	...	...	...	...	×	...	...	...	...	...
Anchura sp. (several species)	×	×	...	...	×	×	...	...	...	?	...	...
Ancyloceras sp.	...	...	...	...	...	...	...	...	...	...	×	×
Anisomyon patelliformis M. & H.	...	...	...	...	...	...	...	...	...	...	×	...
Anisomyon sp.	?	...	...	...	...	...	...	...	?	...	...	?
Anomia sp.	×	...	...	×	...	×	...	...	×	×	×	×
Arca sp.	×	...	?	...	...	...	...	×	...	...	...	×
Astarte sp.	...	...	...	...	...	×	...	...	...	...	...	...
Avicula gastrodes Meek	×	...	...	...	...	...	...	...	...	...	...	...
Avicula linguiformis E. & S.	...	...	...	×	...	...	...	...	...	...	...	...
Avicula sp.	...	...	...	...	...	...	...	...	×	...	...	×
Baculites anceps var. *obtusus* Meek	...	...	...	...	...	...	×	×	...	...	...	...
" *asper* Morton	...	...	?	...	...	×	...	...	...	...	...	...
" *compressus* Say	...	...	...	...	...	...	×	...	...	...	×	×
" *gracilis* Shumard	?	...	...	...	...	...	...	...	...	...	...	...
" *ovatus* Say	...	...	?	...	...	...	...	...	...	...	×	×
" sp.	...	...	×	...	...	×	...	...	×	...	...	...
Callista deweyi M. & H.	...	...	...	...	...	...	×	...	...	...	...	...
Callista pellucida	...	...	...	...	...	...	×	...	...	...	...	...
Camptonectes symmetrica Herrick & Johnson	×	...	...	...	...	...	...	...	...	...	...	...
Cardium bellulum Meek	...	...	...	...	...	...	×	...	...	...	...	...
" *speciosum* M. & H.	...	...	...	...	...	...	×	...	...	...	×	...
" sp. (several species)	×	×	...	×	×	×	...	×	×	×	...	...
" sp. (large)	...	...	...	...	...	...	...	...	×	...	...	...
" sp. (small)	...	...	...	...	...	...	...	...	×	...	...	...
Cinulia ? sp.	×	...	...	...	...	...	...	...	...	...	...	...
Coilopoceras colleti Hyatt	×	...	...	...	×	...	...	...	...	...	...	...
Corbicula sp.	...	...	...	...	...	...	×	...	...	...	...	...
Corbula sp.	×	...	...	×	...	×	...	...	×	...	...	...
Crassatellites cimarronensis White	...	...	...	...	...	...	...	...	...	...	...	×
" *shumardi* Meek	...	...	...	...	...	×	...	...	...	×	...	...
" sp.	...	×	...	?	...	...	...	...	...	...	...	...
Cucullæa sp.	...	...	...	×	...	×	..	×	×	...	...	×
Cyprimeria sp.	?	...	...	×	...	×	...	?	×	×	...	...
Dentalium sp.	...	...	...	...	...	×	×	...	×	...	...	...
Exogyra columbella Meek	×	×	...	...	...	...	...	...	×	...	...	...
" *ponderosa* Roemer	...	...	...	...	...	×	...	...	...	...	...	...

Table of Distribution of Cretaceous Invertebrates—Continued

	Mancos						Mesaverde				Lewis	Pierre and Trinidad
	Lower		Upper									
	Rio Puerco	Hagan and Cerrillos	Durango	Cabezon	Rio Puerco[5]	Cerrillos	Durango	Cabezon	Rio Puerco	Hagan	Dulce	Raton
	1	2	3	4	5	6	7	8	9	10	11	12
Exogyra sp.				×								
Fasciolaria (*Piestochilus*) sp.												×
Fasciolaria sp.							×			?		×
Fish scales											×	
Fish vertebræ										×		×
Fusus sp.	×						×				?	
Gervilliopsis ? sp.	×											
Gryphæa newberryi Stanton	?	×			×							
Gyrodes sp.		×		×		×		×	×	×		
Haminea sp.											×	
Hamites sp.						×						
Heteroceras cheyennense M. & H.												×
Heteroceras sp.	×							×				×
Inoceramus sp. cf. *I. acuteplicatus* Stanton										×		
" *barabini* Morton			×	?			×			×		×
" sp. cf. *I. barabini* Morton						×						
" sp. cf. *I. deformis* Meek									×			
" *dimidius* White		×										
" sp. cf. *I. dimidius* White		×										
" *dimidius* var. *labiatoides* S. & B.												
" *erectus* Meek												
" sp. cf. *I. erectus* Meek									×			
" *fragilis* H. & M.	×	×										
" *irregularis* Johnson						×						
" *labiatus* Schloth		×										
" *oblongus* Meek											?	×
" *sagensis* Owen			×			×					×	×
" *vanuxemi* M. & H.												×
" sp. cf. *I. proximus* Tuomey						×						
" sp.	×		×			×			×	×		×
Isocardia sp.	×	×			×							
Lamna sp. (shark's teeth)				×					×	×		
Leda sp.	×					×	×			×		×
Legumen sp. cf. *L. planulatum* Conrad										×		
Legumen sp.	×					?						?
Liopeplum sp.				×		×						
Lima sp.		×										×
Liopistha (*Cymella*) *undata* M. & H.				?		×		×	?	×	?	×
" (*Psilomya*) sp.	×											
" (") *concentrica* Stanton	×											
Lithophagus sp.									?	×		
Lucina occidentalis (Morton)											×	×
Lucina sp.	×						×					×
Lunatia concinna (H. & M.)												

Table of Distribution of Cretaceous Invertebrates—Continued

	Mancos						Mesaverde				Lewis	Pierre and Trinidad
	Lower		Upper									
	Rio Puerco	Hagan and Cerrillos	Durango	Cabezon	Rio Puerco[5]	Cerrillos	Durango	Cabezon	Rio Puerco	Hagan	Dulce	Raton
	1	2	3	4	5	6	7	8	9	10	11	12
Lunatia sp.	×						×			×	×	×
Mactra alta M. and H.							×					
Mactra sp. cf. *M. formosa* M. & H.				×					×	×		
" sp. cf. *M. gracilis* M. & H.										×		
" *warrenana* M. & H.												×
" sp. (large form)									×			
" sp.		×				×		×	×	×	?	×
Martesia ? sp.												×
Metoicoceras sp. cf. *swallovi* (Shumard)					×							
Metoicoceras sp.	×				×							
Modiola sp.										×	×	
Mortoniceras sp. cf. *M. delawarense* (Morton)						×						
Mosasaurus sp.												×
Mytilus sp.				×								?
Nautilus dekayi Morton						×				?		×
Nautilus sp.						×						
Nemodon sp.												×
Nucula sp.						×		×				×
Odontobasis sp.							×					?
Odontofusus ? sp.										×		
Ostrea congesta Conrad									×			
" *elegantula* Newb.				?		?				×		
" *inornata*							×					
" *lugubris* Conrad	×	×			×							
" sp. cf. *O. lugubris* Conrad		×								×		
" *patina* M. & H.												×
" *pellucida* M. & H.							×				?	
" *subtrigonalis* E. & S.							×					
" (*Alectryonia*) sp.										×		
" sp.	×	×				×			×	×	×	×
Pachydiscus n. sp.		×										
Panopæa sp.	×						×					?
Pectem sp.	×	×			×							
Pholadomya sp.	×	×										
Physa ? sp.									×			
Pinna lakesi White											?	
Pinna petrina White	×	×			×							
Pinna sp.	×	×		×			×			×		
Placenticeras intercalare M. & H.							×				×	×
" *planum* Hyatt						×			×	×		
" *sancarlosense* Hyatt				?		×		×	?	×		
" *whitfieldi* Hyatt											×	×
" sp.		×				×		×				×
" sp. (large form)						×						
Plicatula sp.	×	×										
Prionocyclus wyomingensis Meek	×	×										

Table of Distribution of Cretaceous Invertebrates—Continued

	Mancos						Mesaverde				Lewis	Pierre and Trinidad
	Lower		Upper									
	Rio Puerco	Hagan and Cerrillos	Durango	Cabezon	Rio Puerco[5]	Cerrillos	Durango	Cabezon	Rio Puerco	Hagan	Dulce	Raton
	1	2	3	4	5	6	7	8	9	10	11	12
Prionotropis woolgari Mantell	...	?	...	...	...	...	...	...	...	...	...	...
" sp.	×	×	...	...	...	...	...	...	...	...	...	...
" sp.	...	×	...	...	...	...	...	...	...	...	...	...
Pterocerella sp.	...	...	...	...	...	...	...	...	...	×	...	...
Ptychodus sp. (fish teeth)	×	...	...	...	...	...	...	...	...	...	...	...
Ptychoceras sp.	...	...	...	...	...	...	...	...	...	...	...	×
Pyrifusus sp.	...	...	...	?	...	...	...	?	...	?	×	×
Pyropsis sp.	...	...	...	...	...	...	...	...	×	?	...	...
Scaphites sp. cf. *S. hippocrepis* Dekay	...	...	...	...	...	×	...	...	...	×	...	...
" " " " *larvæformis* M. & H.	...	...	...	×	...	...	...	...	...	...	...	...
" *nodosus* Owen	...	...	...	...	...	...	...	...	...	...	×	×
" sp. cf. *S. nodosus* Owen	...	...	...	...	...	...	...	...	×	...	...	...
" *warreni* M. & H.	×	×	...	...	...	...	...	...	...	...	...	...
" sp.	...	...	×	...	...	...	...	...	...	...	...	×
Serpula sp.	×	...	...	...	...	...	×	...	...	...	...	...
Sphæriola sp.	...	...	...	...	...	...	×	...	...	...	...	?
Stantonoceras pseudocostatum Johnson	...	...	...	?	...	×	...	...	...	...	...	...
Syncyclonema rigida H. & M.	...	...	×	...	...	...	...	...	...	...	×	...
Syncyclonema sp.	...	...	...	...	...	...	...	...	...	×	×	×
Tellina scitula M. & H.	...	...	...	...	...	...	...	...	...	...	...	×
" ? sp.	...	...	...	...	...	...	...	...	...	...	...	×
" sp.	...	...	...	×	...	...	...	...	×	×	×	×
Thetis circularis M. & H.	...	...	...	.	...	...	...	...	...	...	×	...
Trigonarca (*Breviarca*) *exigua* M. & H.	...	...	...	...	...	...	...	...	...	...	×	...
" sp.	×	...	...	...	×	...	...	...	...	...	...	...
Tritonium kanabense Stanton	×	...	...	...	...	...	...	...	...	...	...	...
Turris sp.	...	...	...	...	...	...	...	...	...	×	...	...
Turritella galisteoensis Johnson	...	...	...	...	...	×	...	...	...	...	...	...
" sp. cf. *T. whitei* Stanton	×	×	...	...	...	...	...	...	...	...	...	...
" sp. (probably several species)	×	×	×	...	×	...	×	...	...	×	...	...
Veniella sp.	×	...	...	...	?	...	...	...	...	...	...	...
Volutoderma dalli (Stanton)	...	×	...	...	...	...	...	...	...	...	...	...
Volutoderma sp.	...	?	...	?	×	?	...	×	...	?	...	×
Volutomorpha novomexicana Herrick & Johnson	...	...	...	...	...	...	...	...	×	×	...	...
Volutomorpha sp.	...	×	...	×	...	...	...	...	...	...	...	...

[5] The upper part of the Mancos in the Rio Puerco field yields the same fauna as that of the lower part of the Mancos farther east. In order to show the differences in age, the column denoting upper Mancos in the Rio Puerco field is placed next to that denoting upper Mancos in the Cerrillos field.

measured sections are described apart from the sections. The species of each lot are named in the descriptions of the several fields given in the latter part of this paper, and the general grouping of them is presented in the preceding table. This table contains only the names of fossils identified by T. W. Stanton from collections made principally by the writer, although a few fossils collected by J. H. Gardner and others in western Colorado and New Mexico have been included. Relatively few of these species have ever been described. This may be of no serious consequence for the purposes of this paper, inasmuch as these species seem to have a somewhat restricted geographical distribution in New Mexico, and their nearest known allies occur far to the southeast in Texas; but it is unfortunate that so well developed a fauna as that shown in the foregoing table can not now be made available by proper descriptions and illustrations for purposes of correlation as stratigraphic work is extended in the coal fields of New Mexico. A few of the species have been described by Herrick and Johnson and by Shimer and Blodgett, and the names given them will be found in the annotated list of publications in the latter part of this paper, but only those species which have been identified in the collections of the United States Geological Survey are included in the table.

Fossil plants occur at certain horizons in the Mesaverde of all the coal fields in central New Mexico, and in some places they are numerous and well preserved, but fossil plants seem to be rare in the Mesaverde of northern New Mexico and southern Colorado. Unfortunately, a large part of the flora consists of undescribed species, so that the lack of specific names in the following table might be interpreted as indicative of poor material, whereas in reality it indicates undescribed species of beautifully preserved leaves. Unlike the invertebrates, whose nearest allies occur far to the south, some of the fossil plants are specifically identical with those from some of the coal fields to the north and east, and others are so strikingly similar to species found in those fields that they indicate essentially the same age. Thus the flora most nearly like that of the Mesaverde of central New Mexico is found at Point of Rocks, Wyoming, and other localities to the north in rocks of recognized Montana age. The correlation with the older coal-bearing formation of the Raton field is nearly as perfect, but since the flora of the Raton field is being critically studied at the time of this writing, no final statement regarding the correlation can be made. However, Doctor Knowlton, who has identified the fossils listed in the following table and who is studying the flora of the Raton field, has kindly made the following statement for use in this paper:

"The fossil plant material from the coal fields of central New Mexico while very extensive is not yet fully worked up—in fact is largely new to science—which accounts for the short lists of species. However, it is not probable that any material change of opinion as regards stratigraphic position is likely to result from the complete elaboration of the material, but rather it is likely to be strengthened by the recognition of a greater number of species common to the various areas.

"Bearing in mind the above limitations, we may first consider the flora of the Raton Mesa region which occurs in association with the lower coal; that is, in the beds below the now well established unconformity. If, as has been suggested, the beds immediately below the Trinidad sandstone are to be correlated with the Lewis shale of the San Juan Basin, then the overlying coal-bearing rocks might on stratigraphic grounds be presumed to belong to the Laramie. The plants found in these beds do not bear out this contention, for they have almost no affinity with the typical Laramie of the Denver Basin, there being only two or three species in common, and these of wide vertical distribution or of doubtful identification. On the other hand, this flora has a positive and unmistakable affinity with the flora of the Mesaverde of the western slope of the mountains, and, to go further afield, with the flora of the Rock Springs coal group (Mesaverde) of Point of Rocks, Wyoming. When we find, as is the case, that such well-marked and hence unmistakable species as *Sequoia brevifolia*, *Woodwardia crenata*, *Ficus speciosissima*, *Ficus 'trinervis,' Ficus wardii*, *Ficus lanceolata*, *Sabal 'grandifolia'* (Geonomites of some writers), *Myrica torreyi*, as well as a number of equally well-marked but unnamed species, in common between this and one or the other of the areas above mentioned, we are inevitably led to the conclusion that they are essentially of the same age.

"On the west side of the mountains in the Cerrillos, Hagan, Tijeras, Rio Puerco, and Cabezon coal fields, the floras under discussion occur mainly in the coal-bearing beds from 400 to 600 feet above the base of the Mesaverde of this region, though some of them also range somewhat higher in the Montana, especially in the Durango field to the north. The relationship between these floras and that at Point of Rocks, Wyoming, is even closer than that already mentioned between the Raton Mesa region and Point of Rocks, by the addition of such forms as *Nelumbo intermedia*, *Trapa microplylla*, *Salix Stantoni?*, etcetera. There can be no doubt, it seems to me, that the floras of the Raton Mesa region, of the central and western New Mexican fields and of the Point of Rocks field, are essentially identical, and hence, *per force*, are of essentially the same age.

"Near Dulce, New Mexico, and near Durango, Colorado, there have been obtained two collections of plants from above the Lewis shale in coal-bearing rocks that have been referred to the so-called 'Laramie' of this region. These collections are very full and embrace a number of easily recognized species—hence their identification is satisfactory and complete. These collections prove clearly that these beds do not belong to the Laramie, since so far as known to the writer, not a single species there present has ever been found in beds of this age. On the other hand, the plants indicate beyond question that they belong to the Montana, there being, for instance, *Ficus speciosissima*, *Ficus* sp. (narrow 3-nerved type), *Ficus* sp. type of *F. lanceolata*, a palm, etcetera,

which link them with the Mesaverde floras to the south and the beds already discussed in the Raton Mesa region. Associated with these, however, and tending to give them a slightly higher position, although still within the Montana, are such forms as *Brachyophyllum*, *Cunninghamites*, *Geinitzia*, *Sequoia*, etcetera, all of which are beyond doubt Montana types never found in the Laramie.

"A number of collections were made by J. H. Gardner in the Ignacio Quadrangle, east of Durango, Colorado, from beds regarded as the 'Laramie' of that area. The plants in these collections, almost species by species, are identical with the forms from Dulce and near Durango, and I have no hesitation in saying that they occupy the same stratigraphic position and are the same in age, viz., Montana."

The Lower Montana age of the principal coal-bearing formation, indicated by the fossil shells, has already been stated in the quotation from Doctor Stanton. The fossil leaves indicate the same age, although some of the species occur at Coalville, Utah, in rocks generally regarded as older than Mesaverde, and others in the so-called "Laramie" above the Lewis shale.

An effort was made to correlate the coal-bearing rocks of central New Mexico with the Mesaverde formation of southwest Colorado, where this formation was originally named. Mr. Schrader traced the typical Mesaverde from Durango eastward and southward around the San Juan Basin, but he was not satisfied that the coal-bearing rocks near Cabezon are to be correlated directly with the typical Mesaverde and he described them as the "Lower Montana group; relation to Mesaverde unknown." However, Doctor Gardner, who later examined the same rocks, referred them definitely to the Mesaverde (110, 115, 116).

The present writer visited the Durango region for the purpose principally of examining the rocks originally named Mesaverde. It was thought that this region would be favorable for the collection of fossil plants, inasmuch as the Mesaverde coal has been extensively mined there. He also examined the coal-bearing formation at Monero, New Mexico, and was convinced, as others have been, that it is equivalent to the Mesaverde of the Durango region. However, it was noted that the Mesaverde at Monero is only a few hundred feet thick, probably about the same as in the Durango region, where it is only 423 feet, while the Mesaverde of Doctor Gardner's Arroyo Torreons section (116, page 178), measured a few miles northwest of Cabezon, is more than 1,300 feet thick. A somewhat hasty examination of the rocks between Monero and Cabezon convince the writer that the base of the Mesaverde as described by Schrader and Gardner is essentially the same at both localities, and that the upper part of it near Cabezon is probably equivalent in age to the lower part of

Table showing the Distribution of Fossil Plants from central and western New Mexico and southwestern Colorado

(The locations of the principal lots are indicated on the accompanying map by means of the locality numbers)

Identified by F. H. Knowlton

	Cerrillos field				Hagan field							Tijeras	Rio Puerco field				Cabezon		Monero	Dulce	Du-rango			
																	San Juan Basin							
United States Geological Survey locality numbers	6017	6018	6019	6021	6022	6023	6024	6025	6026	6028	6030	6032	6034	6035	6036	6037	6038	6039	6041	6042	6043	6044	6046	6048
Alga					×																			
Abietites dubius Lesq																		×						
Aralia ? sp			×																					
Brachyphyllum macrocarpum Newb																				×				
Brachyphyllum sp				×			×				×		?						×					
Carpites n. sp					×																			
Celastrus n. sp				×																				
Cunninghamites sp. ?																				×				
Cyperacites sp					×																			
Dalbergia n. sp											×			×										
Diospyros sp																	×							
Dombeyopsis ? sp																	×							
Dryophyllum falcatum Ward														×										
Dryopteris n. sp																	×							
Ficus lanceolata Heer				×		×		×	×	×										×		×		×
" *planicostata* Lesq			×						×											×				
" *rhamnoides* Kn			×																					
" *speciosissima* Ward			?	×			×	?	×							?	×					×		
" *trinervis* Kn															×							×		
" *uncata* Lesq			×																					
" cf. *F. Wardii* Kn										×														
" n. sp. (3-nerved)				×		×	×						?	×			×			×		×		
" n. sp										×							×		×					
" sp											×		?	×							×			×
Equisetum sp																					×			
Eucalyptus sp																	×							
Geinitzia formosa Heer																				×				
" sp	×																							
Geonomites sp			×																			×	×	
Gleichenia sp					?																			
Laurus ? sp												×												
Myrica Torreyi ? Lesq												×												
" sp																	×							
" ? n. sp																			×					
Nelumbo intermedia ? Kn		×			×																			
Palmocarpon commune ? Lesq			×																					
Protophyllocladus sp						×										×								
Quercus sp			?											×							×			
" n. sp						×																×		
Salix stantoni ? Kn														×										
" ? sp													×											
Sequoia reichenbachi (Gein) Heer																				×	×			
Trapa ? *microphylla* Lesq					×																			
Typha sp																×								
Viburnum ? *problematicum* Kn														×										
" sp										×														
Zizyphus n. sp																				×				

the Lewis as developed near Monero. The coal-bearing formation of the Rio Puerco field is essentially equivalent to the Mesaverde of the San Juan Basin, but includes at its base rocks equivalent in age to the upper part of the Mancos shale. It may be stated in brief that, except for the

variations previously noted in the upper and lower limits of the formation, the coal-bearing rocks of all of the fields described in the Rio Grande Valley are lithologically, stratigraphically, faunally, and florally identical with the Mesaverde of the San Juan Basin.

LEWIS SHALE

The Lewis shale is known to occur in the region described in this paper only in the San Juan Basin. It is 1,600 feet thick near Durango, on the northern rim of this basin, and possibly thicker in some other places. According to Mr. Schrader (100, page 242), its maximum thickness is 2,500 feet. It thins rapidly southward, and at its outcrop, in the southern portions of the basin, is about 200 feet thick (116, page 171). Doctor Gardner states (110) that it is 2,000 feet thick near Gallina, but that in Arroyo Torreons, about 30 miles southwest of Gallina, it is only 250 feet thick. No explanation of this great variation in thickness can be given, but the suggestion previously noted seems pertinent that the Lewis may become sandy and coal-bearing to the south, and thus be equivalent in age to the upper portion of the Mesaverde of the Cabezon region. In this connection it may be noted that a shale of marine origin nearly twice as thick as the Lewis of the Arroyo Torreons section occurs in the midst of the Mesaverde in the Rio Puerco field, and that a sandy shale of marine origin of nearly the same thickness occurs in the Tijeras field above the principal group of coals. Because the fossils from these shales do not differ notably from those of the coal-bearing rocks above and below them, the shales are regarded as probably parts of the Mesaverde formation. However, it is entirely possible that when the faunas and floras of this region are better known some of the rocks here described as Mesaverde may prove to be equivalent in age to a part of the Lewis shale.

Few fossils have hitherto been collected from the Lewis shale of the southwest. *Baculites asper* (73, page 5) was found in it in southwest Colorado, and Doctor Gardner found a few fossil shells in it southeast of Raton Springs (locality number 4455 of the accompanying map). These, together with the shells collected by the present writer near Dulce (localities numbers 7200 and 7201), seem to make rather definite the correlation of the Lewis shale with the top of the Pierre of the Raton coal field, east of the Rocky Mountains. The fossils are named and their relation to those collected in the Raton field indicated in the table of invertebrates previously given.

"LARAMIE" FORMATION

The "Laramie" formation occurs within the area described in this paper only in the San Juan Basin. It is more than 1,000 feet thick near

Durango and nearly as thick in the southern rim of the basin (110, page 338), but is thinner in the eastern rim, probably due to the post-Cretaceous erosion. At Dulce it is only 225 feet thick. This formation lies conformably on Lewis shale, and probably for this reason more than for any other has been called Laramie, although Doctor Cross (75, page 4) several years ago called attention to the fact that investigation had "failed to bring to light valid ground for assigning any of the beds in question to the Laramie, while there is some reason to believe that more than the lower sandstone belongs to the Montana group." Since that time a considerable number of fossils, both of invertebrates and of plants, have been collected from these beds in the Durango region. The base of the formation—the Pictured Cliffs sandstone—contains marine invertebrates, and the lower part of the coal-bearing rocks above this sandstone contains brackish-water invertebrates, several of which occur in the Mesaverde of other fields. But higher in the formation the rocks contain fresh-water invertebrates which Doctor Stanton regards as Laramie and fossil plants which Doctor Knowlton regards as older than Laramie. The fossil plants have been included in the table previously given (page 606), and from this table, as well as from the accompanying statement by Doctor Knowlton, it will be seen that the flora differs but little from that of the Mesaverde farther to the south.

The name "Laramie" is here used for this formation not because the writer wishes to argue for the Laramie age of the rocks, but because the name is in use and because in this paper the writer is intentionally avoiding the introduction of new names for rock formations. It must be noted, however, that while the formation is called "Laramie" it contains a flora which denotes Montana age, having nothing in common with the Laramie flora of the Denver Basin.

Whether the formation will eventually be called Laramie or be designated in some other way depends largely on the final use of that somewhat migratory name. But in view of the fact that many of the species of marine and brackish-water invertebrates from the lower part of the formation occur in the Mesaverde of other localities; that the invertebrates from the upper part are of fresh-water origin and admittedly unreliable for purposes of correlation, and that the plants are of Montana types, serious doubt is cast on the Laramie age of the formation.

TERTIARY AND LATER FORMATIONS

It is not the purpose of the writer to enter into a discussion of the Tertiary and later formations of New Mexico farther than is necessary to show that in all of the coal fields described rocks of probable Tertiary age lie unconformably on "Laramie" or older rocks. In the Durango

region the "Laramie" is succeeded unconformably by the Animas formation, which has been regarded generally as the time equivalent of the Denver. Some geologists still refer these formations to the Cretaceous, but G. B. Richardson (122) has recently shown in a manner rather convincing to many geologists that the Denver formation is of Tertiary age. He referred the Dawson arkose to the Eocene, and since, according to Doctor Knowlton, the "leaves from the lower part of the Dawson . . . are undoubtedly Denver in age," the Denver must of necessity be of the same age as the Dawson, namely, Eocene. Rocks that seem to be equivalent in age to the Animas rest unconformably on the "Laramie" near Dulce, New Mexico, and farther to the south in the San Juan Basin the oldest Tertiary rocks—the Puerco formation—lie unconformably on the "Laramie" in some places and on the Lewis shale in other places (117).

In the Rio Puerco field rocks that are lithologically similar to the Wasatch of the San Juan Basin rest unconformably on the Mesaverde. They are varicolored, with yellow, pink, and red shales predominating, and although they have never been measured they are comparable in thickness to the Tertiary formations of that basin. These rocks consist of poorly consolidated sandstone, conglomerate, and shale. The upper part is light colored and seems to be referable to the Sana Fe marls, the type locality of which is a few miles east of the Rio Puerco field.

No rocks referable to the Tertiary were found in the Tijeras field, but in the Hagan field a series of beds comparable in thickness, lithologic character, and general appearance to the Tertiary of the Rio Puerco field rest unconformably on the Mesaverde. These beds contain great quantities of petrified wood, but no fossils were found in them that make possible the determination of their age. The Hagan and Rio Puerco fields are only about 30 miles apart, and it is difficult to believe that the rocks of these two fields, which are comparable in every other way, differ in age to any great extent.

In the Cerrillos field rocks that are lithologically similar to the Tertiary rocks of the Hagan and Rio Puerco fields and of the San Juan Basin lie unconformably on the Mesaverde. This is known as the Galisteo sandstone. The lower part of this formation consists of conglomeratic sandstone and shale identical in character and appearance to those of the Hagan field 10 miles to the west, but the upper parts are coarser and contain large angular blocks of many kinds of rock, including quartzite, and crystalline rocks such as are now exposed in the mountains a few miles to the northeast; limestone, containing Carboniferous fossils, sandstone, etcetera. Rock formations, from which these were probably derived, are now found upturned and eroded on the flanks of the mountains. The Galisteo sandstone is many hundreds of feet in thickness and

may include more than one formation, but it has not been studied with a view to subdividing it into formations or of making exact correlations with formations of other fields. These rocks are the so-called "Cretaceous red beds" of the Cerillos region, which some geologists have correlated with the Denver formation. Hayden (19), who named this formation, regarded it as Tertiary and correlated it with the Monument Creek of the Denver region, the lower part of which has recently been named the Dawson arkose (122) and correlated with the Arapahoe and Denver formations. J. J. Stevenson (53) failed to separate the Galisteo from the underlying coal measures and referred both formations to the Laramie. D. W. Johnson (83) also failed to recognize the unconformity at the base and included the lower part of the Galisteo sandstone in his Madrid group, which he referred to the Fox Hills. He referred the upper part to the Laramie. Nothing has been found in the Galisteo to establish its geologic age. It contains great numbers of petrified logs, which are beautifully preserved in external form, but the cellular structure of the wood is not well preserved and no specific identifications have been made. The best known locality at which these logs occur is a few miles east of Cerrillos, in the so-called petrified forest, where there are many logs 25 to 75 feet or more in length. But logs have been found in this formation in many other places in a state of preservation much better than that of the logs near Cerrillos. Fossil leaves have also been found in a few places, but their preservation is poor and few have been specifically identified. All things considered, it is probable that the Galisteo sandstone should be correlated with those Tertiary formations farther west that are similar to it in character and stratigraphic position. This relation is indicated by the correlation lines in figure 2, page 597.

Correlation with the Raton Section

The Raton coal field is located in northern New Mexico, east of the Rocky Mountains, and is separated from the San Juan Basin by a mountainous area about 90 miles wide. The Cretaceous and younger formations of this field were described three years ago by the writer (111) as consisting of Dakota sandstone, a shale equivalent in age to Benton, Niobrara, and Pierre; the Trinidad sandstone, a coal-bearing formation called "Laramie or older (?)," and a younger coal-bearing formation of post-Laramie age lying unconformably on the older one. Up to that time these coal-bearing formations had been grouped together under the name Laramie. Two years later the writer (119) traced them around the Raton and Trinidad coal fields and found them unconformable in all parts of the Raton Mesa region. During the later investigation a large

volume of data was obtained which is not yet ready for publication. Great numbers of fossil plants were collected from both coal-bearing formations, and a special study of them is being made by F. H. Knowlton. Although his study is not complete, it has progressed so far that he feels justified in stating definitely that the plants from the two formations constitute two distinct floras; that the upper one is post-Laramie in age, and that the lower one, formerly (111) called "Laramie or older (?)," is clearly Montana and older than recognized Laramie. Inasmuch as the study of these floras is incomplete, it is thought best to withhold the lists of species. The rock formations of this field and their relations to each other are shown in the following section:

Generalized Section of Rocks in the Raton Coal Field, New Mexico

	Feet
Sandstone and shale, conglomeratic at the base, coal-bearing, containing fossil plants of post-Laramie age	1,600±
(Unconformity.)	
Sandstone and shale, coal-bearing, containing fossil plants which Knowlton regards as older than Laramie	0–475
Sandstone (Trinidad) containing *Anomia*? sp.; fish bones; *Halymenites major* Lesq.; *Inoceramus barabini* Morton; *Inoceramus sagensis* Owen; *Inoceramus* sp.; *Legumen?* sp.; *Mactra warrenana* M. and H.; *Mactra*? sp.; *Mytilus*? sp.; *Panopæa*? sp.; *Tellina scitula* M. and H.; *Tellina* sp.	100±
Shale with concretions and thin layers of limestone. Near the top the shale contains the following Pierre fossils: *Ancyloceras* sp.; *Anisomyon?* sp.; *Anomia* sp.; *Arca* sp.; *Avicula* sp.; *Baculites ovatus* Say; *Baculites compressus* Say; *Crassatellites cimarronensis* White; *Fasciolaria* (*Piestochilus*) sp.; *Fasciolaria* sp.; *Heteroceras cheyensis* M. and H.; *Heteroceras* sp.; *Inoceramus barabini* Morton; *Inoceramus oblongus* Meek; *Inoceramus sagensis* Owen; *Inoceramus vanuxemi* M. and H.; *Inoceramus* sp.; *Leda* sp.; *Lima* sp.; *Liopistha* (Cymella) *undata* M. and H.; *Lucina occidentalis* (Morton)?; *Lucina* sp.; *Lunatia* sp.; *Mactra* sp.; *Martesia*? sp.; *Mosasaur* bones; *Nautilus dekayi* Morton; *Nemodon* sp.; *Odontobasis*? sp.; *Ostrea patina* M. and H.; *Ostrea* sp.; *Placenticeras intercalare* M. and H.; *Placenticeras whitfieldi* Hyatt?; *Placenticeras* sp.; *Ptychoceras* sp.; *Pyrifusus?* sp.; *Scaphites nodosus* Owen; *Scaphites* sp.; *Syncyclonema* sp. The lower part of the shale contains Benton and Niobrara fossils. The following were collected in the Raton field: *Baculites asper* Morton; *Coilopoceras novimexicanum* Hyatt; *Inoceramus dimidius* White; *Inoceramus fragilis* H. and M.?; *Inoceramus labiatus* Schlotheim; *Inoceramus* sp.; *Ostrea lugubris* Conrad; *Ostrea* sp.; *Prionocyclus wyomingensis* Meek; *Scaphites ventricosus* M. and H.	3,000±
Sandstone (Dakota).	
Total	5,175

The lower part of the shale overlying the Dakota sandstone is clearly of Benton age, and Niobrara is probably also represented, although these formations are not so clearly separable as they are in southern Colorado. The upper part of the shale contains a Pierre fauna, but it is not certain that this fauna is indicative of latest Pierre time. On the other hand, it contains a fauna very similar to that of the Lewis shale at Dulce on the opposite side of the mountains. If it be assumed that the highest coal-bearing rocks at Dulce are of Laramie age, the correlation would make the top of the Pierre of the Raton field and the top of the Lewis at Dulce equivalent to highest Montana and tend to place the lower coal group of the Raton field in the Laramie; but the fossil plants above the marine rocks at both localities indicate Montana rather than Laramie age. It is, therefore, probable that the shale does not at either locality represent latest Montana time.

Some geologists have referred the Trinidad sandstone to the Fox Hills, but no unquestioned Fox Hills is known south of Colorado Springs. The fossils of the Trinidad, named in the foregoing section, belong to the Montana fauna, but are not of distinctive Fox Hills species. This fact indicates that the Trinidad may be equivalent in age to some part of the Pierre of other localities, and that Fox Hills time may be represented by something younger than Trinidad, perhaps in part by rocks that were entirely removed during the post-Cretaceous erosion. The flora of the lower coal measures, described as Montana in age and similar to that of the Mesaverde of the central New Mexico fields, resembles in a lesser degree the flora of the so-called "Laramie" of southwest Colorado and northwest New Mexico—a flora which Doctor Knowlton maintains is "Montana and not Laramie." The evidence seems to indicate that the coal measures below the unconformity in the Raton field belong in the Montana somewhere between the Mesaverde of the central New Mexico fields and the so-called "Laramie" of northwestern New Mexico.

Post-Cretaceous Unconformity

Evidence has previously been presented (111 and 119) to prove that the unconformity in the Raton field is equivalent in time to the post-Laramie unconformity of the Denver Basin, and that the erosion represented by it was comparable in amount in the two regions. The youngest rocks left in the Raton field by this erosion are the Montana coal measures. If younger Cretaceous formations ever existed there, they were eroded away. The formation next above the unconformity is correlated by fossils as well as by stratigraphic position with the Arapahoe and Denver formations.

In the Cerrillos and Hagan fields, which may be considered together, inasmuch as they are separated only on account of faulting, the unconformity is probably equivalent in time to that in the fields just mentioned. It separates rocks of Montana age—the Mesaverde—from those which have been correlated with the Denver formation and which are shown in this paper to be probably equivalent to the Tertiary formations of the San Juan Basin. The interval of erosion was comparable in duration to that of the Raton and the Denver regions, inasmuch as the older sedimentary rocks in the mountains were eroded down to the ancient crystallines, as is shown by the presence in beds immediately above the unconformity of pebbles of all of these rocks.

In the Rio Puerco field also the unconformity separates the Mesaverde formation from rocks of Tertiary age, and a few miles farther north, in the vicinity of Cuba, Tertiary rocks that are lithologically the same as those of the Rio Puerco field lie unconformably on Mesaverde and older rocks and also on the Lewis shale and the "Laramie" formations. Farther north at Dulce the Tertiary rocks lie unconformably on the "Laramie." The relations of the Tertiary to the older rocks in the several fields described in this paper are indicated in figure 2, and the relations of the formations near Dulce to those of the Raton field and to the intervening mountains are shown in the sketch section, figure 3.

The possible objection to the postulate that the unconformities in all these fields have not been proved to be exact time equivalents may be met by the equally valid argument that there is no proof to the contrary. In no place do rocks younger than Cretaceous occur below the unconformity, nor do any rocks of undoubted Cretaceous age occur above it. From a diastrophic viewpoint, this unconformity is the logical plane of separation between the Cretaceous and the Tertiary in the Rocky Mountain region. The same plain of separation is indicated by the fossil plants. Those below the unconformity in all of the fields described belong to the Montana flora, while those above it are of Tertiary types.

The correlation of the unconformities in the various fields is based largely on a broad conception of the physical conditions existing in the Rocky Mountain region during late Cretaceous time. This is too large a subject to be discussed here, but it is generally agreed by geologists that in early Cretaceous time the area now occupied by the Rocky Mountains was one of very low relief if not actually baseleveled. It is not improbable that the Cretaceous formations once extended over much if not the entire area now occupied by the Rocky Mountains. This conception is wholly in agreement with the observed relations in New Mexico. The Cretaceous formations are comparable in thickness and in lithologic char-

acter on either side of the mountains and sediments above the Dakota sandstone, varying in thickness from 1,000 to more than 2,000 feet, give little indicaton that they were derived from a land-mass in the Rocky Mountain area rather than from land-masses at greater distances. Inasmuch as the remnants of them are now separated by a distance of less than 90 miles, as shown in figure 3, it seems reasonable to assume that they once extended continuously over the area now occupied by the mountains. Although minor warpings of the surface may have occurred, causing differences in the thickness of these sediments, or even causing slight emergencies in some places, there seems to have been no orogenic disturbance in the mountain region before the close of the Cretaceous which left any unmistakable imprint on the stratigraphic record. At the close of the Cretaceous the first great upheaval of the mountains occurred and erosion naturally began on all sides of them. It is recorded on the east, south, and west sides by the post-Cretaceous unconformity described in this paper. The period of erosion was sufficiently long to remove thousands of feet of consolidated rock, and doubtless the sediments thus derived accumulated in formations that are transitional in time between Cretaceous and Tertiary. Such formations should be found at a distance from the mountains, while those above the unconformity near the mountains should represent time somewhat later than the beginning of the Tertiary.

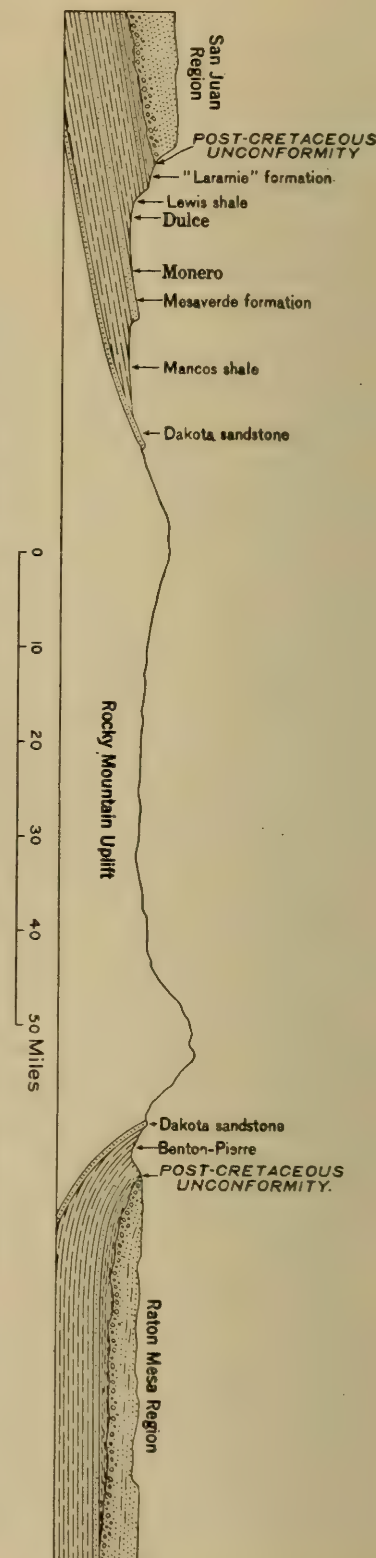


FIGURE 3.—*Sketch Section through the Raton Mesa and San Juan River Regions*

The area is near the boundary between Colorado and New Mexico, and the sketch section shows the occurrence of a post-Cretaceous unconformity on either side of the Rocky Mountains.

Descriptive Details

MONERO AND DULCE

The details noted in the Durango region have been given in the description of the type section. The next place east of Durango in which the writer made observations is between Chama and Dulce, on the Denver and Rio Grande Railroad, in northern New Mexico. Here the Dakota sandstone was observed in a small canyon about 2 miles southeast of Chama. The Mancos shale occupies a broad valley between Chama and Monero, and near its base is a sandy zone, which represents in a general way the Tres Hermanos sandstone typically developed farther south. The writer collected no fossils from the Mancos in northern New Mexico, but Schrader obtained *Inoceramus fragilis* H. & M., *Scaphites warreni* M. & H., and *Prionocyclus wyomingensis* Meek from a locality on Chama River 2 miles northwest of Elvado, New Mexico, at a horizon estimated by him to be about the middle of this shale. According to Doctor Stanton, these fossils denote Upper Benton age.

Just east of Monero the railroad passes through a sharp canyon in which the basal sandstone of the Mesaverde forms conspicuous cliffs. The westward dip of the rocks brings the coal beds that overlie this basal sandstone down to the level of the railroad at Monero, where the coal has been mined for many years. The Mesaverde here does not differ notably in character from the Mesaverde of the Durango region, and according to Schrader (100), was traced from Durango to Monero.

A few very poorly preserved leaves were found associated with the Mesaverde coals near Monero. They are *Brachyphyllum* sp., *Myrica* or *Eucalyptus* (n. sp.), and *Ficus* n. sp. The fossil plants seem to be restricted to very narrow zones, and the sandstone both below and above the coal beds contains marine fossils. *Ostrea* sp., *Pecten* sp., *Inoceramus barabini* Morton, and *Baculites anceps* var. *obtusus* Meek (United States Geological Society locality number 7206) were collected near Monero from a sandstone a few feet above the highest bed of coal.

The Lewis shale occupies a broad valley between Monero and Dulce. Its thickness was estimated at 1,000 feet, but this estimate may be too low, inasmuch as the measured thickness both west and south of Monero is 2,000 to 2,500 feet (100, page 242) and (110, page 339). Schrader traced this shale continuously around the northern rim of the San Juan Basin, and thus proved it to be the eastward extension of the typical Lewis shale. About half a mile north of Dulce this shale is very fossiliferous, and the following shells were collected from it at two horizons. They occur in limestone concretions distributed somewhat sparingly

through the upper half of the shale, which is perfectly exposed in a steep barren slope. The first lot (7200) of the following list is from the upper 100 feet, and the second lot (7201) is from a horizon 300 to 500 feet below the top of the shale.

Shells collected from the Shale Slope about half a Mile North of Dulce, New Mexico

United States Geological Survey locality numbers....	(7200)	(7201)
Ostrea pellucida M. & H.?		×
" sp.	×	
Anomia sp.		×
Syncyclonema rigida H. & M.		×
" sp.	×	
Inoceramus sagensis Owen	×	×
" *oblongus* Meek?		×
Modiola sp.	×	
Cardium speciosum M. & H.	×	
Pinna lakesi White?		×
Trigonarca (Breviarca) exigua M. & H.		×
Lucina occidentalis (Morton)		×
Thetis circularis M. & H.	×	×
Pyrifusus sp.		×
Tellina sp.	×	
Mactra? sp.	×	
Liopistha undata M. & H.	×	
Lunatia sp.	×	
Fusus? sp.	×	×
Anysomyon patelliformis M. & H.		×
Actæon sp.	×	×
Haminea sp.		×
Baculites ovatus Say		×
" *compressus* Say		×
Ancyloceras sp.		×
Scaphites nodosus Owen		×
Placenticeras whitfieldi Hyatt	×	×
" *intercalare* M. & H.		×
Fish scales		×

There is above the Lewis shale a series of rocks not less than 1,000 feet thick, somewhat shaly in the lower part, where a thin bed of coal occurs, but consisting principally of massive sandstone more or less conglomeratic throughout. Apparently some of the older geologists referred this whole series to the Laramie. Others referred some of it to the Laramie and some to the Tertiary. Schrader (100) described the lower or coal-bearing portion as "Laramie," and proved, by tracing the beds, that it is identical with the "Laramie" of the Durango region. The following

fossil plants were found by the present writer a few feet above the coal both north and south of the railroad near Dulce:

Fossil Plants collected from the "Laramie" near Dulce, New Mexico

(United States Geological Survey locality number 6042)

(Those marked (*) occur also in the "Laramie" near Durango, Colorado)

Brachyphyllum macrocarpum Newb.
Sequoia reichenbachi (Gein.) Heer
Cunninghamites sp.?
Geinitzia formosa Heer
Palm (same as species at Point of Rocks)
Ficus planicostata ? Lesq. (same as species at Point of Rocks)
Ficus n. sp. (3-nerved)
Ficus lanceolata Heer
Zizyphus n. sp.

(The names *Brachyphyllum macrocarpum*, *Sequoia reichenbachi*, *Geinitzia formosa*, *Ficus* n. sp. and *Ficus lanceolata* are marked with an asterisk on the page.)

The flora is essentially the same as that described from the "Laramie" of the Durango section, and confirms the statement that the beds are of the same age. It also strengthens Doctor Knowlton's opinion, previously quoted, that the beds may be older than Laramie, inasmuch as two of the species are found at Point of Rocks, Wyoming, in a formation regarded as older than Laramie, and others are found in the Mesaverde at the localities farther south, described in this paper. In commenting on these plants, Knowlton says: "Their age is essentially Montana and not Laramie. If uninfluenced by their apparent stratigraphic position, I should incline to place them in the Mesaverde, but since they are above Lewis they obviously can not be Mesaverde, though they can be—and in my opinion are—still Montana."

The writer found no invertebrates in the "Laramie" near Dulce, but J. H. Gardner collected some from this formation near Pagosa Junction, about 15 miles northwest of Dulce. They are as follows:

Fossils collected in southeast One-quarter, Section 19, Township 34 North, Range 4 West, near Pagosa Junction, Colorado, 5 feet above Laramie (?) Coal Number 1

Ostrea subtrigonalis E. & S.	*Corbicula cytheriformis* M. & H.
Anomia sp. cf. *A. micronema* Meek	*Corbula undifera* Meek

The rocks above the Lewis shale in the Dulce area, referable to the Cretaceous, are only about 225 feet thick, including the basal sandstone, which is 60 feet thick. A section of them and of the rocks underlying them was measured in the steep canyon wall about a mile northwest of Dulce. At this locality a conglomerate that varies greatly in thickness

and character within short distances rests unconformably on the coal-bearing rocks. For about 75 feet above this basal conglomerate the rock is variable in lithologic character and consists of friable, granular sandstone and shale, irregularly intermingled, and in it are many lenses and irregular masses of conglomerate. The whole mass is dark colored and gives the impression of being the erosional product of a mass of dark-colored igneous rock. The suggestion is offered that this formation may represent the Animas formation of the Durango region, although its stratigraphic position would tend to make it somewhat older than the Animas.

Section of Rocks measured about one Mile Northwest of Dulce, New Mexico

	Feet
Sandstone, conglomeratic, brown	80+
Sandstone, slightly shaly, with greenish tint at base; massive, yellow above	44
Shale and sandstone, yellow	121
Sandstone, shaly, greenish	6
Conglomerate with pebbles, principally of chert, up to one-half inch in diameter	12
Sandstone, shaly, gray	27
Conglomerate with chert pebbles up to three-quarters inch in diameter	28
Shale, sandy, yellow	8
Sandstone, white	3
Shale, sandy, yellow	10
Conglomerate with chert pebbles up to three-quarters inch in diameter	38
Shale, sandy, yellow	18
Sandstone, massive, coarse-grained, yellow	66
Shale, sandy, dark-colored	21
Sandstone, friable, dark-colored	46
Sandstone, coarse-grained, conglomeratic, with pebbles mostly of chert up to an inch or more in diameter	6
(Unconformity by erosion.)	
Shale, sandy, carbonaceous; contains fossil leaves (U. S. G. S. locality No. 6042)	83
Coal, coke, and intruded igneous rock	8
Sandstone, coarse-grained, light-colored	66
Shale, sandy	8
Sandstone, massive, light-colored	60
Shale (Lewis), fossiliferous (U. S. G. S. locality Nos. 7200 and 7201)	300+
Total	1,059

The writer found no fossils in rocks above the unconformity, but other geologists seem to have been more fortunate. J. H. Gardner, who is familiar with this region, has, at the writer's request, furnished the following information in a letter dated December 26, 1911:

"I have carried a reconnaissance survey around the north side of the San Juan Basin and have done the details of the Ignacio folio which lies to the west but on the rim of the same basin. There is no doubt in my mind, based on reconnaissance mapping and lithological similarity, that the beds to which you refer (those above the unconformity) are Animas. . . . The heavy conglomerate beds at the base of the Animas are in the form of a lentil which thins out away from the Animas Valley. The beds above this consist of tan-colored and greenish shale alternating with coarse-grained, tan-colored sandstone containing grains of igneous origin. . . . The beds which are intruded with sills along the canyon and cross-cut by dikes (the upper 461 feet of the foregoing section) are of the same nature and apparently connect with the upper beds of the Animas. They are older than the Puerco and Torrejon, and contain remains of Triceratops."

CABEZON

The writer made few observations between Dulce and Cabezon, a distance of about 90 miles. Doctor Gardner (116) correlated the rock formations exposed near Cabezon with those of the Durango region and gave them the same names, namely, Mancos, Mesaverde, Lewis, and "Laramie." The correlation is based on the work of tracing the outcrops of these formations around the San Juan Basin from their type locality in southwest Colorado. They are described as more or less continuously exposed on the west and south sides of the basin, but for a short distance west of Nacimienta Mountains they are covered by overlapping Tertiary rocks. However, in spite of the great length of outcrop around the basin to the west and the area of obscured outcrops on the east side, Doctor Gardner seems to have felt confident that the formations near Cabezon are to be correlated directly with those of the Durango section. He collected fossils from both the Lewis shale and the Mesaverde formations. They are among the United States Geological Survey collections and have been identified by T. W. Stanton. Two collections were obtained from the Lewis as follows:

Invertebrates collected by J. H. Gardner from about 100 Feet below the Top of the Lewis Shale about 6 Miles Southeast of Raton Spring, New Mexico

(United States Geological Survey locality number 4455)

Ostrea sp.	*Liopistha undata* M. & H.
Cardium speciosum M. & H.	*Lunatia* sp.
Legumen sp.	*Melania?* sp.

Invertebrates collected from the Lewis Shale by J. H. Gardner two and one-half Miles Southeast of Cuba, New Mexico

(United States Geological Survey locality number 4452)

Inoceramus barabini Morton	*Placenticeras intercalare* M. & H.
Baculites compressus Say	

His Mesaverde fossils, collected near Cuba, are as follows:

Invertebrates collected near the Base of the Mesaverde Formation, three-quarters of a Mile North of Copper City, New Mexico

(United States Geological Survey locality number 4453)

Nucula sp.
Cucullæa sp.
Arca sp.
Cardium sp.
Cyprimeria? sp.
Liopistha undata M. & H.
Mactra sp.
Gyrodes sp.
Pyrifusus? sp.
Volutoderma sp.
Actæon sp.
Baculites anceps var. *obtusus* Meek
Placenticeras intercalare M. & H.
Placenticeras sp.
Heliococeras sp.
Scaphites sp. related to *S. larvæformis* M. & H.

While in the field the present writer assumed that the Mesaverde age of the coal measures near Cabezon was established, and his purpose in visiting this locality was to collect fossils from the Mesaverde for the purpose of correlating with it the coal-bearing rocks which in the fields farther east contain similar fossils. A large number of petrified logs and stumps of trees were found in the lower part of the Mesaverde north of Cabezon, and leaf impressions occur in the same beds, but most of these were too poorly preserved for identification. However, beautifully preserved leaves were found in a thin layer of fine-grained sandstone about 400 feet above the lowest bed of coal. The locality is about 5 miles northwest of Cabezon, in a steep bluff half a mile north of a small artificial lake. The species collected are as follows:

Fossil Plants collected from the Mesaverde Formation, North 43 Degrees West from Cabezon Butte

(United States Geological Survey locality number 6038)

Ficus speciosissima Ward
Ficus n. sp. (3-nerved)
Dryopteris n. sp. (same species found in lower group of coal beds at Canyon City, Colorado)
Dyospyros sp.
Ficus n. sp.
Myrica sp.
Eucalyptus sp.
Dombeyopsis? sp.
Two or three undescribed dicotyledons

Fragments of palm leaves were found 50 to 100 feet above the bed yielding these plants, but no fragment was found with the parts necessary for the identification of species. Still higher in the formation, at the

east end of Chacra Mesa, several conifers of the species *Abietites dubius* Lesq. were found.

Two small collections of shells were made from the Mancos shale near Cabezon. One was obtained from the sandy layers at the top of the formation in the transitional zone between the Mancos and the basal sandstone of the Mesaverde. They were found at the point where the wagon road leading northwestward from Cabezon crosses the top of the Mancos shale. They are as follows:

Fossils from the Top of the Mancos Shale, Northwest of Cabezon

(United States Geological Survey locality number 7194)

Ostrea elegantula Newberry ?
Anomia sp.
Pinna sp.
Cardium sp.
Cyprimeria sp.
Tellina sp.
Liopistha undata M. & H. ?
Mactra sp., related to *M. formosa* M. & H.
Corbula sp.
Gyrodes sp.
Actæon sp.
Placenticeras sancarlosense Hyatt.

The second collection was obtained from the low hill back of the town of Cabezon at a horizon several hundred feet below the top of the Mancos shale. The rocks containing them are somewhat sandy, and this fact may serve to explain the resemblance of the fauna to that yielded by the sandstones of the Mesaverde. The fossils are as follows:

Fossil Shells collected at Cabezon, New Mexico
(United States Geological Survey locality number 7195)

Exogyra sp.
Anomia sp.
Avicula linguiformis E. & S.
Inoceramus barabini Morton?
Mytilus sp.
Cucullæa sp.
Crassatellites ? sp.
Cyprimeria sp.
Gyrodes sp.
Volutomorpha sp.
Volutoderma ? sp.
Liopeplum sp.
Pyrifusus ? sp.
Placenticeras sancarlosense Hyatt?
Stantonoceras pseudocostatum Johnson?
Lamna sp. (shark's teeth)

From a study of fossils collected from the Mancos, in the vicinity of Cabezon, Shimer and Blodgett (109, page 58) arrived at the conclusion that the shale was of Benton age. They found many Benton species associated with a few which they regarded as belonging to the Pierre fauna. However, the exact horizons of their collections are not known to the present writer, and it is possible that they may be somewhat lower than the horizons at which the fossils named above were found. In the light of the more recent investigations, Doctor Stanton is of the opinion that

these fossils belong to the fauna occurring in the coal measures in the Rio Puerco field, which in turn are referred by him to the lower part of the Montana.

Shimer and Blodgett describe the Mancos shale from several localities between Cabezon and the Rio Puerco field. They report a characteristic Benton fauna from low in the shale corresponding to the Concretion (Septaria) zone of Herrick and Johnson, and a separate fauna from higher in this shale supposed to correspond in general with the Caphalopod zone of Herrick and Johnson. The upper zone of these writers contains a large number of Benton species, together with a few which they regard as characteristic of the Pierre (see 109). Their work serves to connect the formations observed near Cabezon with those of the Rio Puerco field, for although the Mesaverde is not continuous between the two fields the Mancos is continuous and the overlying Mesaverde occurs in Prieta Mesa and probably also at Cabezon Butte, so that there are only three short breaks in its continuity between the large area occupied by this formation in the San Juan Basin and the smaller area in Rio Puerco field.

RIO PUERCO FIELD

Aside from brief references in the accounts of early explorations to the occurrence of coal, the first geologic information of the Rio Puerco coal field was given by Herrick and Johnson (77). The various zones described by them and the fossils contained in each zone are named in the notes of the annotated list of publications (77) in the latter part of this paper. These zones were found convenient for use by the present writer and are here used in a quotational way.

The Cretaceous rocks of this field dip toward the east, the degree of dip varying greatly from place to place, and disappear under a cover of Tertiary and Quaternary rocks in the Rio Grande Valley. A section showing the main features of the Cretaceous rocks below the Mesaverde was measured near San Francisco. The line along which the measurements were made extends across the gently dipping rocks from the Dakota (?) outcrop northwest of San Francisco to Punta de la Mesa farther to the south. The fossils collected from the several horizons are named in the section:

Section of Rocks measured in the Rio Puerco Coal Field near San Francisco, New Mexico

	Feet
Sandstone, massive, yellow (Punta de la Mesa sandstone or base of Mesaverde)	77
Shale, sandy at top	240±
Limestone, shaly, containing *Ostrea lugubris* Conrad and *Coilopoceras colleti* Hyatt (U. S. G. S. locality No. 3515)	10±

	Feet
Shale	50
Shale with limestone concretions (Cephalopod zone) containing *Pinna petrina* White?; *Pecten* sp.; *Trigonarca* sp.; *Isocardia* sp.; *Veniella ?* sp.; *Cardium* sp.; *Turritella* sp.; *Volutoderma* sp.; undetermined gastropods; *Metoicoceras* sp. related to *M. swallovi* (Shumard); *Metoicoceras* sp. (U. S. G. S. locality No. 3520)	10±
Shale. In the lower part were found *Ostrea* sp.; *Avicula gastrodes* Meek; *Pinna petrina* White; *Veniella* sp.; *Pholadomya* sp.; *Turritella* sp. related to *T. whitei* Stanton; *Metoicoceras* sp. (U. S. G. S. locality No. 7191). The fossils were collected at some distance from the line of measurement of the section and may possibly belong to the Cephaloped zone	600±
Sandstone, shaly, with impure limestone in lenses and concretions. (This sandstone and the limestone concretions above and below it seem to constitute the Concretion (Septaria) zone of Herrick and Johnson.) It contains *Ostrea* sp.; *Exogyra columbella* Meek; *Anomia* sp.; *Avicula gastrodes* Meek; *Cardium* sp.; *Legumen* sp.; *Pecten* sp.; *Pinna petrina* White; *Isocardia* sp.; *Liopistha* (*Psilomya*) sp.; *Anchura* sp.; *Prionotropis* sp.; *Acanthoceras* ? sp. (U. S. G. S. locality Nos. 7192 and 3513)	50×
Shale alternating with layers of yellow sandstone	78
Shale, carbonaceous, dark-colored; has general aspect of the shale associated with the coal beds of the Mesaverde in this field	2
Sandstone, coarse-grained above, shaly below; weathers to irregular, rounded masses; contains *Halymenites* similar to *H. major* Lesq., worm borings, and a variety of indefinite markings	25
Shale, dark-colored (Gastropod zone), containing *Ostrea* sp.; *Exogyra columbella* Meek; *Camptonectes symmetrica* Herrick and Johnson; *Plicatula* sp.; *Gervilliopsis* ? sp.; *Pinna petrina* White; *Pinna* sp.; *Liopistha* (*Psilomya*) sp.; *Arca* sp.; *Trigonarca* sp.; *Cardium* sp.; *Lucina* sp.; *Turritella* sp.; *Anchura fusiformis* White non Meek; *Anchura* sp.; *Cinulia* ? sp.; *Serpula* sp. (U. S. G. S. locality Nos. 7205, 3517, and 3518)	35
Sandstone, soft, friable; contains small pebbles, principally of quartz and chert	5
Sandstone, yellow	8
(Abrupt change in lithology.)	
Sandstone, coarse-grained, gray to pink; varies greatly from place to place in thickness, composition, and color. This sandstone has the stratigraphic position of the Dakota, but its color and variable character are suggestive of Morrison	100
Sandstone and shale, variegated (Morrison).	
	1,290

Two collections of fossils were made east of the Rio Puerco about 3 miles north of San Francisco. The first is from a zone of limestone concretions that seems to occupy a horizon about 50 feet above the top of the

Tres Hermanos sandstone. The following species were collected at this locality:

Fossil Shells collected East of the Rio Puerco, about 3 Miles North of San Francisco, New Mexico

(United States Geological Survey locality number 7204)

Ostrea sp.	*Turritella* sp.
Pinna petrina White	*Prionotropis* sp.
Cardium sp.	*Metoicoceras* sp.
Lunatia sp.	*Coilopoceras colleti* Hyatt

The second collection is from an exposure about half a mile east of the first and estimated to be stratigraphically higher by about 100 feet. The strata here dip very slightly to the east and the rocks are covered with soil in most places. The shells collected at the higher horizon are as follows:

Shells collected East of the Rio Puerco, about 3 Miles North of San Francisco, New Mexico

(United States Geological Survey locality number 7193)

Ostrea lugubris Conrad	*Baculites gracilis* Shumard?
Anomia sp.	*Prionocyclus wyomingensis* Meek
Inoceramus fragilis H. & M.	*Scaphites warreni* M. & H.
Anchura sp.	*Ptychodus* sp. (fish teeth)
Anisomyon ? sp.	

These fossils seem to indicate horizons several hundred feet above the base of the Mancos, namely, near the Caphalopod zone, whereas their apparent position as observed in the field is near the base of the Mancos about 500 feet below the Caphalopod zone. It is possible that the rocks have been faulted, so that the position of this zone in the section is deceptive, but no indication of faults with displacement of more than 25 feet was noted near these localities.

More detailed investigation of the Mancos from Rio Puerco westward is necessary before its subdivisions and their relations to each other and to neighboring formations are properly understood. The rocks dip at low angles and broad grassy valleys occur at the outcrops of the shale. The rocks are faulted and warped in some parts of this field, and it is difficult to find a place where there is no liability of error in measuring the shale in these broad valleys. Furthermore, the fauna is not so well known that the vertical range of all the species can be confidently given. A section measured by Darton (114, page 60) near Laguna, at the southwestern extremity of the area shown on the accompanying map, is

given. The fossils seen indicate a position near the base of the Mancos about the horizon of the Tres Hermanos sandstone, and yet they occur above a body of shale much thicker than any reported elsewhere below this sandstone.

Section of Part of Cretaceous Rocks 2 Miles Northeast of Laguna, New Mexico

Measured by N. H. Darton

	Feet
Lava	..
Sandstone	25
Shale	60
Sandstone, buff, massive, moderately soft	40
Shale with sandstone layers, very fossiliferous; contains *Exogyra columbella* Meek; *Gryphæa* sp.; probably a variety of *G. newberryi; Avicula gastrodes* Meek?; *Cardium* sp.; *Panopea* sp.; *Turritella* sp.; *Rostellites volutoderma* sp., and *Fusus* sp	..
Sandstone, massive, hard, light buff	40
Shale, dark gray to gray-green, sandy layers fossiliferous; contains *Exogyra columbella* Meek; *Pecten* sp.; *Pinna petrina* White; *Inoceramus* ? sp.; *Leda* sp.; *Cardium* sp.; *Lucina* ? sp.; *Isocardia* n. sp.; *Cyprimeria?* sp.; *Corbula* sp.; *Liopistha* (*Psilomya*) *concentrica* Stanton; *Turritella whitei* Stanton; *Tritonium Kanabense* Stanton; *Actæon* sp.; *Cinulia* sp.; *Turrilites?* sp., or *Heteroceras* sp	60
Sandstone, hard, red, irony	5
Sandstone, white, massive, part coarse	80
Shale, greenish gray, sandy above	235
Sandstone, hard, buff, massive	40
Shale, soft	30
Sandstone (basal bed of Cretaceous)	..
Total	490

No place was found where a complete detailed section of the Mesaverde formation of the Rio Puerco field could be measured. The beds are well exposed in only a few places, and where they are exposed some of them are warped to such an extent that it is difficult to trace individual beds for any considerable distance, and others are faulted so that certain beds are duplicated; also, some of the upper part of the formation seems to have been removed by erosion previous to the deposition of the overlying Tertiary rocks, inasmuch as the lowest bed observed in the Tertiary is a conglomerate. A generalized section was measured east of the Rio Puerco, about 3 miles north of San Ygnacio, where many fossils were collected. A section of the upper part of the coal-bearing rocks was measured in detail about a mile farther north by L. C. Chapman, who was assisting the writer in doing the field work. This has been incorporated in the general section below. Where the section was measured,

faulting has occurred in a way that renders the relation of the Mesaverde to the Tertiary open to question; but near the northern end of the Rio Puerco field an exposure was found of rocks undisturbed by faulting where the basal conglomerate of the Tertiary with pebbles of quartzite up to 6 inches in diameter rests on the Mesaverde.

Section of Mesaverde Rocks measured near San Ygnacio, New Mexico

	Feet	Inches
Sandstone, locally conglomeratic, and shale (Tertiary) poorly consolidated, vari-colored, with reds predominating below and milder shades above (many hundreds of feet)	..	..
Probable unconformity	..	..
Shale with thin beds of coal; absent in some places	0-10	..
Sandstone, massive, yellow, calcareous, and shaly in some places; contains *Ostrea* sp., *Anomia* sp., *Inoceramus* sp. (thick-shelled); *Cucullœa* sp.; *Cardium* sp. (large form); *Cardium* sp. (slender form); *Tellina* sp.; *Cyprimeria* sp.; *Liopistha undata* M. & H.?; *Corbula* sp.; *Mactra* sp., related to *M. formosa* M. & H.; *Mactra* sp. (large form); *Dentalium* sp.; *Gyrodes* sp.; *Physa* ? sp.; *Volutomorpha novimexicana* Herrick & Johnson; *Pyropsis* sp.; *Actœon* ? sp.; *Scapnites* sp., related to *S. nodosus* Owen; *Placenticeras sancarlosense* Hyatt?; *Placenticeras planum* Hyatt? (U. S. G. S. locality No. 7189)	300±	
Shale, sandy, containing *Brachyphyllum* ? sp.; *Ficus* n. sp. (3-nerved type); *Salix* ? sp.; *Ficus* ? sp. (large leaf) (U. S. G. S. locality No. 6034)	9	..
Shale, carbonaceous	11	..
Coal	1	1
Shale, carbonaceous	7	..
Sandstone	8	..
Shale, carbonaceous	2	6
Coal	..	7
Shale, carbonaceous	3	6
Sandstone	3	..
Coal	..	1
Shale, carbonaceous	7	..
Coal	..	6
Shale, carbonaceous	10	..
Coal	..	2
Shale, carbonaceous	2	6
Sandstone	1	..
Shale	6	..
Coal	..	5
Shale, carbonaceous	3	6
Coal	..	2
Shale, sandy	2	6
Coal	1	..
Shale, sandy	..	6

	Feet	Inches
Shale	2	6
Coal	1	1
Shale, carbonaceous	9	..
Shale	1	6
Coal	..	5
Shale, carbonaceous	5	..
Coal	..	5
Shale, carbonaceous	2	..
Coal	..	3
Shale, carbonaceous	3	..
Sandstone, coarse-grained	2	..
Shale, carbonaceous	3	..
Coal	1	2
Shale, carbonaceous	15	..
Coal	..	5
Shale, carbonaceous	4	..
Coal	1	9
Shale, sandy, carbonaceous	8	..
Shale, sandy	1	..
Shale, carbonaceous	2	6
Sandstone, coarse-grained, gray	3	..
Shale, carbonaceous, chocolate-colored	5	..
Coal	..	2
Shale, carbonaceous, chocolate-colored	1	6
Sandstone, coarse-grained, massive, gray	30	..
Shale, with layers and lenses of yellow sandstone and earthy limestone containing *Halymenites major* Lesq.; *Ostrea congesta* Conrad; *Inoceramus* sp.; *Lithophagus* ? sp.; *Lamna* sp. (U. S. G. S. locality No. 7190)	400±	..
Sandstone, coarse-grained, yellow to gray; contains the following fossil leaves: *Quercus* sp. serrate, new; *Ficus* n. sp. (3-nerved type); *Ficus* sp.; *Dryophyllum falcatum* Ward (Point of Rocks species); *Dalbergia* n. sp. (same as Hagan No. 6030); *Salix stantoni* ? Kn.; *Viburnum* ? *problematicus* Kn. (U. S. G. S. locality No. 6035)	25±	..
Shale, containing one bed of coal 6 feet thick and several thin beds	100±	..
Sandstone with layers of shale and lenses of impure limestone, fossiliferous, but no collections made	172	..
Sandstone, massive, gray, with lenses of impure yellow limestone near the top, containing *Ostrea* sp.; *Inoceramus* sp. (very thick-shelled form); *Cucullœa* sp.; *Cardium* sp.; *Tellina* sp.; *Liopistha undata* M. & H.?; *Mactra* sp. related to *M. formosa* M. and H.; *Mactra* sp., large form; *Volutomorpha novimexicana* Herrick & Johnson; *Baculites* sp.; *Placenticeras planum* Hyatt; *Lamna* sp. (U. S. G. S. locality No. 7188)	110	..
Shale, carbonaceous, chocolate-colored	27	..
Sandstone, yellow, and shale, in alternating layers	235	..

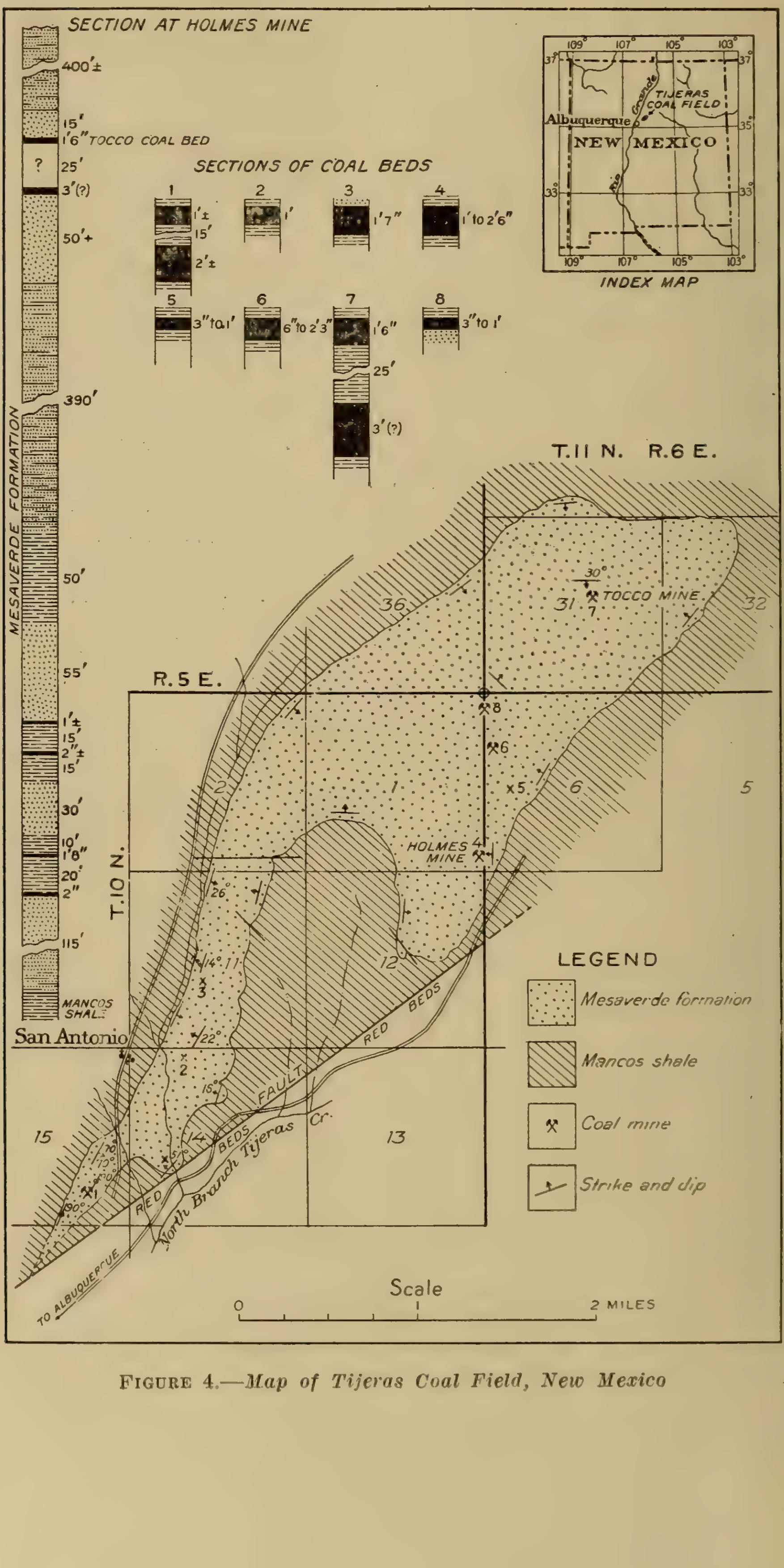


FIGURE 4.—*Map of Tijeras Coal Field, New Mexico*

	Feet	Inches
Shale, yellow to chocolate-colored	57	..
Shale, carbonaceous	5	..
Sandstone, massive, yellow (Punta de la Mesa sandstone), containing *Inoceramus deformis* Meek?; *Avicula* sp.; *Mactra* sp.; *Cardium* sp.; *Anisomyon?* sp.; *Cyprimeria?* sp. (U. S. G. S. locality Nos. 3514 and 3519)	77	..
	1,703	8

TIJERAS COAL FIELD

The Tijeras coal field is located in central New Mexico, about 14 miles south of Hagan and 20 miles east of Albuquerque, on the eastern slope of the Sandia Mountains. The coal-bearing rocks occupy the center of a syncline of irregular outline about 5 miles long and 2 miles wide (see figure 4), lying between the Sandia uplift on the west, the South Mountain uplift on the northeast, and a broad but less well defined uplift on the southeast, which manifests itself within the area mapped by a fault which brings the Carboniferous red beds in contact with the Mancos shale. The coal-bearing rocks are much disturbed by faulting, warping, and crushing, but in general dip from all directions toward the center of the syncline. Along the western margin of the field the strata are upturned to a nearly vertical position. Across the edges of these upturned beds at San Antonio the part of the accompanying section below the coal beds was measured. In the central part of the syncline, although the rocks lie more or less horizontal, they are warped, faulted, and crushed to such an extent that any measurement of their thickness is likely to be deceptive. The part of the accompanying section above the Mancos shale was measured in a canyon at Holmes mine near the center of the syncline, where the rocks seem to be disturbed less than they are in some other places. Nevertheless, the section is given here with some hesitancy because the measured thickness may prove to be quite different from the thicknesses of the beds as originally laid down. The section as measured is as follows:

Section of Rocks measured in the Tijeras Coal Field, New Mexico

		Feet	Inches
Mesaverde or younger	Sandstone, coarse-grained (not continuously exposed, thickness estimated)	400±	..
	Sandstone, gray, coarse-grained, friable; contains fossil leaves *Laurus* ? sp	15	..
	Coal	1	6
	Not exposed	25	..
	Coal	3±	..
	Not exposed	?	..
	Sandstone, coarse-grained, hard, cliff-making (thickness estimated)	50	..
	(Abrupt change in lithology)		
	Shale and yellow sandstone. The shale predominates in the lower part and the sandstone above; contains *Ostrea* sp.; *Inoceramus barabini* Morton?; *Cucullœa* sp.; *Cyprimeria* sp.; *Legumen* ? sp.; *Gyrodes* sp.; *Volutomorpha novimexicana* Herrick and Johnson ?; *Fusus* ? sp.; *Odontofusus ?* sp. (U. S. G. S. locality No. 7187)	390	..
	Shale, with many thin layers of yellow flaggy sandstone	50	..
Mesaverde	Sandstone, massive; contains *Ostrea* sp.; *Inoceramus* sp.; *Cucullœa* sp.; *Cyprimeria* sp.; *Volutomorpha* sp.; *Pyropsis* sp.; *Placenticeras planum* Hyatt; *Placenticeras sancarlosense* Hyatt; *Baculites* sp.; *Sphenodiscus* ? sp.; *Lama* ? sp. (U. S. G. S. locality No. 7182 and 7185)	55±	..
	Coal with a thin layer of shale containing *Ficus* sp. above it	1±	..
	Shale	15	..
	Coal	2±	..
	Shale, not continuously exposed	15	..
	Sandstone, massive; contains *Ostrea* sp.; *Cucullœa* sp.; *Cucullœa* ? sp.; *Cardium* sp.; *Cyprimeria* sp.; *Mactra* sp.; *Gyrodes* sp.; *Volutomorpha novimexicana* Herrick and Johnson; *Placenticeras sancarlosense* Hyatt (U. S. G. S. locality No. 7184)	30	..
	Shale, with *Myrica torreyi* ? and other plants	10	..
	Coal	1	8
	Shale and sandstone, with thin layers of coal; contains *Cucullœa* sp. and *Cardium* sp	20	..
	Coal	..	2±
	Sandstone, massive, cliff-making; contains *Cardium* sp.; *Callista* ? sp.; *Volutomorpha* sp. (U. S. G. S. locality No. 7186)	115	..

		Feet	Inches
Mancos	Shale, dark-colored, sandy at the top	1,345	..
Mancos	Sandstone (Tres Hermanos), hard, quartzose; contains worm borings and indefinite markings of various kinds	145	..
Mancos	Shale, dark-colored, with limestone concretions (Gastropod zone)	60	..
	Sandstone (Dakota)	65	..
	Sandstone and shale, variegated (Morrison)	..	..
		2,812	6

The rocks of the Morrison formation are not well exposed, but where seen near San Antonio do not differ in character from those referred to the Morrison at other localities in central New Mexico. They rest on the gypsiferous red beds of the Manzano group of the Pennsylvanian series (112).

The Dakota sandstone is hard and quartzose, and, together with the Tres Hermanos sandstone, forms a prominent double ridge along the western side of the field where the rocks are upturned to a nearly vertical position. The dark-colored shale of the Gastropod zone is present at this locality, but it is thinner here than it is farther to the north in the Hagan and Cerrillos coal fields. The concretions of limestone found in many places in this shale, and which contain numerous fossils on the Rio Puerco and elsewhere, were observed at San Antonio, but no fossils were collected from them.

A sandstone 145 feet thick occurs above the shale containing the Gastropod zone. No fossils were found in it, but it is stratigraphically and lithologically the same as the Tres Hermanos sandstone of the other fields described in this paper.

The principal mass of the Mancos shale is thinner in the Tijeras field than it is in the Hagan and Cerrillos fields, but this may be due in part to mechanical thinning which may have taken place during the disturbance which upturned the rocks. On the other hand, it may be that the shale originally thinned toward the south as it does toward the west, but the distance of 10 miles between the fields is scarcely enough to render this hypothesis tenable.

There are no fossiliferous lenses of yellow sandstone below the coal beds in the Tijeras field as there are in the Hagan field. It has not been determined whether this absence is to be explained on the assumption that the top of the Mancos shale of the Tijeras field is equivalent to the sandstone lenses of the Hagan field or whether the coal-bearing rocks of the Tijeras field are equivalent in age to the lenses of the Hagan field

and therefore older than the Hagan coals. In many places in the Tijeras field the basal sandstone of the Mesaverde contains marine shells of species identical with those found in the sandstone below the coal in the Hagan field. Coal lies immediately above this sandstone, and associated with it are fossil plants, but only a few poorly preserved specimens were found. The Mesaverde of the Tijeras field is essentially a marine formation and shells were collected from it at several horizons, as indicated in the section.

There is a zone of shale and sandstone above the principal coal beds which contains marine fossils and which may be the equivalent of the Lewis shale of the southern part of the San Juan Basin described by Gardner (116). It is somewhat thicker than the Lewis in the southeastern part of this basin, the locality nearest to the Tijeras field at which the Lewis is known to occur. The fossils named in the accompanying section indicate clearly the marine character of these beds, and if the Tijeras section were compared only with the sections measured in the Hagan and Cerrillos fields to the north it would seem proper to correlate the coal-bearing rocks with the coal measures of the Hagan and Cerrillos sections and refer the marine beds above them to a higher horizon not now represented in the Hagan and Cerrillos fields. On the other hand, if the Tijeras section be compared with that of the Rio Puerco field, it appears that the rocks containing these marine shells may represent one of the marine horizons known to occur within the Mesaverde in that field. The fossil shells seem to favor the latter correlation, for they are not characteristic Lewis species. They do not differ materially from those found at several horizons within the Mesaverde, and because of this fact these rocks are included in the Mesaverde.

These marine beds are overlain by a coarse-grained, hard, cliff-making sandstone, which differs in character and appearance from the sandstone below to such an extent that it suggests the beginning of a new formation. This in turn is overlain by coal-bearing sandstone and shale. If the underlying beds containing the fossils of marine origin prove to be Lewis the higher beds may be regarded as Laramie. No fossils except a few poorly preserved plants were found in them, and these proved to be insufficient for the determination of age. These younger coal-bearing rocks are confined to the trough in the center of the syncline and occupy an area of only a few acres. Coal occurs near the base of the formation, but the rocks intervening between it and the basal sandstone, which is relatively hard, consist of soft sandstone and shale so poorly exposed that the thickness could not be measured. Two coal beds separated by an interval of 25 feet are known to occur in this upper coal-bearing formation.

They were observed at the Tocco coal mine. The rocks above these coal beds consist principally of coarse-grained, friable sandstone, and like the basal sandstone just described are very different in appearance from any of the sandstones associated with the lower coal beds in this field or in the Mesaverde formation of the neighboring fields. For this reason these rocks are regarded as possibly younger than Mesaverde.

HAGAN FIELD

The Hagan coal field lies east of the Rio Grande between the Sandia and the Ortiz Mountains. The Hagan coal mine, from which this field derives its name, is located about 14 miles southwest of Cerrillos. This mine has been described by M. R. Campbell (103, page 429), and the coal beds correlated by him and others with those opened in the same field at the Sloan and the Pina Vititos mines. The rocks of this field dip east at angles varying from 15 to 35 degrees and disappear under accumulations of rock debris of comparatively recent origin. A section of the Cretaceous rocks at Hagan was measured with tapeline across the strike in an east-west direction, and the thicknesses given in the accompanying section were obtained by correcting for dip the distances measured at the outcrop. The rocks lying stratigraphically below the Dakota were described by the writer (112, figure 2, page 19) a few years ago, the top of the section measured at that time coinciding with the base of the following section. The two may be combined to make a complete section of the sedimentary rocks exposed east of the Sandia Mountains.

Section of Rocks measured near Hagan, New Mexico

		Feet	Inches
Recent	Conglomerate consisting of pebbles and boulders up to several feet in diameter (several hundred feet)		
	(Unconformity.)		
Tertiary (?)	Shale and friable sandstone, highly colored in many shades of purple, blue, green, yellow, etc.	2,500	
	Sandstone, conglomeratic, with partings of red shale; a coarse conglomerate occurs at the base. The sandstone is all coarse-grained, granular, and friable	195	
	Shale, sandy in some places, gypsiferous; highly colored like the shale above	750	
	Sandstone, yellow, conglomeratic at the base with pebbles up to 4 inches in diameter in a matrix of loose, friable sandstone. Pebbles consist principally of quartz, quartzite, chert, jasper; sandstone like those of lower horizons and fragments of petrified wood. Sandstone is very		

		Feet	Inches
Tertiary (?)	coarse-grained and more or less friable throughout, and contains great numbers of petrified logs, some of which seem to be of palm wood. Concretions of pink sandstone occur in the lower part	345	
	(Probable unconformity.)		
Mesaverde	Shale, sandy, with soft, friable sandstone. The shale is carbonaceous with thin seams of coal in many places, and several coal beds 1 to 6 inches thick occur near the top. Large concretions of yellow and chocolate-colored, calcareous sandstone, yellow cone-in-cone structure limestone, and ironstone throughout. The following fossil plants were found at the top of this shale half a mile north of Hagan: *Brachyphyllum* sp.; *Ficus* sp.; *Dalbergia* n. sp. (U. S. G. S. locality No. 6030)	600	
	Sandstone in thick, massive plates; forms the crest of the ridge at Hagan mine; fossiliferous.	120	
	Shale, sandy; contains crystals of gypsum and fossiliferous concretions of sandstone. Fossil plants at the top are *Alga; Cyperacites* sp.; *Gleichenia* ? sp.; *Trapa* ? *microphylla* Lesq.; *Nelumbo intermedia* ? Kn.; *Carpites* n. sp. (U. S. G. S. locality No. 6022)	34	
	Coal	1	
	Shale, chocolate-colored	..	6
	Coal	1	
	Sandstone, gray to brown, hard, fine-grained, in layers alternating with shale	12	
	Shale, sandy, gray	3	
	Coal	1	
	Sandstone and shale in alternating layers; contains *Protophyllocladus* sp.; *Ficus lanceolata* Heer; *Ficus* n. sp. (3-nerved); *Quercus* sp. (U. S. G. S. locality No. 6023), 6 to 15 feet	10	
	Sandstone, massive, gray, cross-grained, cross-bedded; contains petrified wood; lies with uneven contact on coal, 5 to 15 feet	10	
	Coal (Hagan mine)	3±	
	Shale, carbonaceous, chocolate-colored	1	
	Sandstone, shaly, and carbonaceous shale	20	
	Sandstone, calcareous, chocolate-colored	4	
	Shale, sandy	25	
	Coal, shaly	1	
	Shale	4	
	Coal	1	6

		Feet	Inches
Mesaverde	Covered. (Thin beds of coal occur at this horizon ½ mile farther north)	82	
	Sandstone, massive, friable, light gray	20	
	Not well exposed. There are several small ridges formed by the outcropping of sandstone layers in which are concretions of chocolate-colored sandstones and fossiliferous limestones; contains *Ostrea elegantula* Newberry; *Ostrea* sp.; *Anomia* sp.; *Syncyclonema* sp.; *Modiola* sp.; *Inoceramus barabini* Morton; *Inoceramus* sp.; *Lithophagus* sp.; *Leda* sp.; *Cucullæa* sp.; *Cardium* sp.; *Legumen* sp. related to *L. planulatum* Conrad; *Liopistha undata* M. and H.; *Tellina* sp.; *Mactra* sp. related to *M. formosa* M. and H.; *Mactra* sp. related to *M. gracilis* M. and H.; *Mactra* sp.; *Turritella* sp.; *Gyrodes* sp.; *Lunatia* sp.; *Pterocerella* sp.; *Fasciolaria* ? sp.; *Turris* sp.; *Pyrifusus* ? sp.; *Pyropsis* ? sp.; *Volutomorpha novimexicana* Herrick and Johnson; *Actæon* sp.; *Placenticeras whitfieldi* Hyatt; *Placenticeras intercalare* M. and H.; *Placenticeras sancarlosense* Hyatt; *Placenticeras planum* Hyatt; *Scaphites* sp. related to *S. hippocrepis* De Kay; *Lamna* sp. (shark's teeth); fish vertebræ (U. S. G. S. localities Nos. 6778 and 7172)	220	
	Shale and sandstone not well exposed	415	
	Sandstone with a subordinate amount of shale. The sandstone occurs in large lenticular masses and contains irregular masses of brownish yellow to chocolate-colored, fossiliferous limestone. Gastropods are most numerous near the base. Contains *Ostrea* sp. related to *O. lugubris* Conrad; *Ostrea* (*Alectryonia*) sp.; *Inoceramus barabini* Morton; *Inoceramus* sp. related to *I. acuteplicatus* Stanton; *Pinna* sp.; *Cucullæa* sp.; *Cardium* sp.; *Crassatellites shumardi* Meek; *Cyprimeria* sp.; *Tellina* sp.; *Turritella* sp.; *Anchura* ? sp.; *Gyrodes* sp.; *Turris* sp.; *Pyrifusus* ? sp.; *Volutomorpha novimexicana* Herrick and Johnson; *Pyropsis* ? sp.; *Odontofusus* ? sp.; *Volutoderma* ? sp.; several undetermined gastropod genera; *Nautilus dekayi* Morton ?; *Placenticeras sancarlosense* Hyatt; *Placenticeras intercalare* M. and H.; *Lamna* sp. (shark's teeth) fish vertebræ (U. S. G. S. localities Nos. 6779 and 7175)	265	

		Feet	Inches
Mancos	Shale with a few layers and concretions of limestone. The upper part, 100 to 200 feet thick, is sandy and yellowish in color, and contains *Anomia* sp.; *Inoceramus* sp. related to *I. acuteplicatus* Stanton; *Inoceramus* sp. related to *I. sagensis* Owen; *Cardium* sp.; *Gyrodes* sp.; *Pyropsis* ? sp.; *Volutomorpha novimexicana* Herrick and Johnson (U. S. G. S. locality Nos. 7171 and 7173); but the principal part is dark-colored and contains few fossils, except a very large species of *Inoceramus*. Thin layers of fossiliferous limestone occur near the base and contain *Inoceramus labiatus* Schloth; *Inoceramus fragilis* H. and M.; *Prionocyclus wyomingensis* Meek (U. S. G. S. locality No. 7178)....	1,405	
	Shale with fossiliferous limestone concretions at the top, containing *Ostrea lugubris* Conrad; *Ostrea* sp.; *Inoceramus labiatus* Schloth.; *Inoceramus fragilis* H. and M.; *Pecten* sp.; *Pinna petrina* White; *Cardium* sp.; *Isocardia* sp.; *Anatina* sp.; *Pholadomya* sp.; *Mactra* ? sp.; *Turritella* sp. related to *T. whitei* Stanton; *Gyrodes* sp.; *Volutoderma dalli* (Stanton); *Actæon* sp.; *Placenticeras* sp.; *Prionotropis*—two or more species (U. S. G. S. locality No. 7177)	400	
	Limestone containing *Inoceramus labiatus* Schloth..................................	1	
	Shale....................................	175	
	Sandstone (Tres Hermanos), quartzose, consisting of thin, contorted layers with numerous worm borings and markings of many kinds; also poorly preserved gastropods and other shells	5	
	Shale (Gastropod zone)........................	90	
	Sandstone (Dakota), white, friable, cross-bedded, locally conglomeratic........................	50	
	Shale (Morrison), variegated, and sandstone....	200	
		7,970	0

The Dakota sandstone is massive, conglomeratic, quartzitic in some places and friable in others, and its thickness changes from 15 to 50 feet or more in relatively short distances. No fossils were found in it, and its reference to the Dakota is based on its similarity in lithologic character and stratigraphic position to the Dakota of neighboring regions.

The Mancos shale here, as elsewhere in the areas described in this paper, includes several more or less well defined members that can be

recognized over wide areas by their lithologic characters and by characteristic fossils. The lowest one, containing the Gastropod zone, so called by Herrick and Johnson (77, page 175), in the Rio Puerco field, is found in a dark-colored shale 90 feet thick, and here, as elsewhere in central New Mexico, contains limestone concretions. However, these are not so fossiliferous as are those of the Gastropod zone on the Rio Puerco. A few imperfect shells, mostly of the genus *Inoceramus,* were seen in it, but none were collected.

The *Tres Hermanos* sandstone (77, page 176) is recognizable in this field, but it is only 5 feet thick where the section was measured. However, it increases to 15 or 20 feet in some places near by. It was observed along the outcrop from a point about 2 miles south of Hagan, northward to Pina Vititos, a distance of about 8 miles, where it disappears under surface debris. It contains a few poorly preserved gastropods and fragments of other shells.

The main body of the Mancos shale overlies the Tres Hermanos sandstone. It was measured and examined with considerable care near Hagan. The lower half of it consists of dark-colored shale containing thin layers and concretions of limestone. The upper half is more or less sandy and weathers to a brownish yellow color. These two subdivisions were readily recognizable throughout the Hagan field. A thin limestone about 175 feet above the base of the shale is full of shells of the species *Inoceramus labiatus,* a characteristic fossil of the Greenhorn limestone. A zone characterized by numerous limestone concretions occurs about 400 feet above this limestone and has been called the Cephalopod zone by Herrick (77, page 177). These concretions are very fossiliferous and yielded the fossils named in the accompanying section (lot number 7177).

In the lower part of this concretion zone a petrified log 10 inches in diameter was found. The interior portions of it are silicified and the silica center is surrounded by an envelope of coal about half an inch thick. Seventy-five feet above the top of the concretion zone the shale contains thin layers of dark-colored limestone containing the fossils named in the accompanying section as lot number 7178. These shells, together with those from the concretion zone below them, belong to the Benton fauna. Several of the species are the same as those that Johnson (81) included in his Benton fauna of the Cerrillos field. The writer visited Johnson's locality near the smelter at Cerrillos and is convinced that the horizon represented there is about the same as that indicated in the accompanying section 75 feet above the Cephalopod zone.

At still higher horizons the Mancos shale contains large Inocerami 18

inches or more in length. The shells are fragile and crumble so easily that none were collected. They appear to be the same species that the writer has observed in many places near the center of the Mancos shale west of the Rocky Mountains and near the middle of the Pierre shale east of these mountains.

The upper part of the Mancos shale formation consists of sandy shale about 700 feet thick which may be the time equivalent of the relatively thin sandy transitional beds at the top of the Mancos in other places. The fossils contained in it (number 7177) do not differ from those of the overlying Mesaverde formation.

The line of separation between the Mancos shale and the Mesaverde formation is here drawn at the base of the massive yellow sandstone above which the coal beds occur. The lower part of this formation is not continuously exposed at Hagan. It consists of sandstones that form prominent ridges and these ridges are separated by depressions in which softer rocks, presumably shale, are poorly exposed. The sandstones are more or less lenticular and no one of them has been traced for any considerable distance. They weather to a rusty yellow color and contain irregular masses of earthy limestone in which great numbers of fossil shells were found. These are named in the accompanying section. They do not differ materially from those found in the shale below. In other words, the rocks here referred, principally on lithologic characters, to the top of the Mancos, and those referred to the base of the Mesaverde are faunally not distinguishable.

The upper part of the coal-bearing rocks of the Mesaverde are well exposed near Hagan mine and contain several beds of coal, two of which have been opened at the mine. Alternating with these beds are layers of carbonaceous shale and chocolate-colored sandstone, in which are fossiliferous concretions of yellow calcareous sandstone similar in general appearance to the concretions at which contain the marine shells at lower horizons. The concretions lying just above the principal opening of the Hagan mine yielded the fossil plants of Mesaverde age (number 6023) named in the section. Leaves and large petrified tree trunks occur at somewhat lower horizons.

The shale between the coal beds contains large crystals of selenite, and this shale, as well as the sandstone associated with it, does not differ in general aspect from the beds of marine origin immediately below the coal. The shaly rocks, about 600 feet thick above the main coal beds, are more variable in constitution than those at lower horizons. The lower part of this shale contains great numbers of concretions of earthy limestone; near the top it is more carbonaceous and in some places contains

several thin beds of coal. These beds have been prospected, but no place was observed where the coal is more than a few inches thick, although a considerable amount of carbonaceous shale was seen.

The measured thickness of 600 feet is probably more than the normal thickness of this shale. The measurement was made across the trough of a tilted syncline and it is possible that the shale has been mechanically thickened. It is not so well exposed and no measurement of its thickness was made farther north, although the interval occupied by it was estimated at considerably less than 600 feet. The rocks at Pina Vititos, which probably represent this shale, were measured as 460 feet thick.

Lying unconformably on these highest coal-bearing rocks is a conglomerate that constitutes the base of an extensive series of rocks younger than the Mesaverde. These rocks are highly colored and consist of shale, sandstone, and conglomerate similar in many ways to the Galisteo sandstone of the Cerrillos coal field, although they differ from the typical Galisteo in being much more shaly; also the conglomerates consist of well rounded pebbles of hard rock, whereas those of the Galisteo sandstone near Cerrillos contain many angular ones and slightly worn blocks of relatively soft rock. However, it should be noted in this connection that the pebbles of the lowest conglomerates near Cerrillos are similar to those in the Hagan field, and that larger and more angular ones are most numerous toward the top of the formation. On the other hand, these colored rocks in the Hagan field are very similar in composition, color, and general appearance to the Tertiary rocks of the Rio Puerco field, 30 miles to the west, and hold the same stratigraphic position. Although it seems probable that these rocks will eventually prove to be the time equivalents of some of the Tertiary formations of the San Juan River region farther west, they are provisionally correlated with the Galisteo sandstone formation. No fossils except petrified wood were found in them. This occurs in the formation at all horizons in the form of tree trunks 1 to 5 feet or more in diameter, and many well worn pebbles of petrified wood, probably derived from tree trunks that were embedded in the eroded portions of the underlying coal measures, were found in the conglomerates.

The youngest rocks near Hagan are coarsely conglomeratic and lie with conspicuous angular unconformity on the eroded edges of the Galisteo (?) red beds northeast of Hagan, on the Mesaverde near Hagan, and on the Mancos shale and the Manzano (Pennsylvanian) red beds farther to the south. They consist principally of blocks of igneous rock derived in recent geologic time mainly from the Ortiz Mountains and constitute part of the formation which in the Cerrillos region was referred by John-

son (83, page 173 et seq.) to the Santa Fe marls and which, according to his definition, included rocks of both Tertiary and Quaternary age. They are the rocks that form the aggraded parts of the high altitude conoplain (90) that has been described from this region.

The Sloan coal mine is located in the Hagan field about 3 miles north of the Hagan mine, and the formations of the Hagan section are all exposed there. The coal beds have been described by M. R. Campbell (103, page 428), who quotes a section of the coal-bearing rocks measured by Charles R. Keyes. The Mancos shale below and the Galisteo (?) formation overlying the Mesaverde are present and are characterized by the same features as those described from Hagan and from Pina Vititos.

The Mesaverde is fossiliferous at several horizons. The massive sandstone underlying the principal coal beds contains *Halymenites major* Lesq. and some of the species of shells that were found in the Mesaverde at Hagan. Fossil leaves, *Ficus speciosissima* Ward, *Ficus* sp. type *F. lanceolata, Ficus* sp. type *F. planecastata,* and several undescribed forms were found in the white sandstone overlying the main bed of coal. These same species were found at about the same horizon in a gulch half a mile south of Sloan mine.

Pina Vititos is the name of a coal mine located at the north end of the Hagan field about 3 miles north of the Sloan mine and about 14 miles west of Cerrillos. All of the formations from Dakota to Tertiary (?) are well exposed in the gulch in which the mine is located. They all dip about 30 degrees east and disappear under a cover of surface debris. Those below the Mesaverde do not differ in kind or character from the Mancos at Hagan and were not examined in detail. A section of the Mesaverde and younger rocks was measured with tapeline in the gulch and the measurements corrected for dip are given in the following section:

Section of Rocks measured at Pina Vititos, New Mexico

		Feet
Recent	Conglomerate and breccia, containing a few pebbles of quartz, chert, etc., but consisting principally of blocks of igneous rock up to 5 feet or more in diameter, cemented to a resistant mass (many hundreds of feet)	..
	Sandstone composed principally of igneous material...	165
	Unconformity...	..

		Feet
Galisteo (?)	Sandstone, friable, slightly colored	330
	Conglomerate composed principally of colored cherts up to 3 inches in diameter	10
	Sandstone, shaly, friable, variegated in color—shades of pink and yellow predominating	460
	Sandstone, friable, shaly, varicolored, with irregular masses of conglomerate at many horizons consisting principally of pebbles of chert; contains great numbers of petrified logs	1,125
	Sandstone, friable, white to light pink in color; contains pebbles of chert throughout	200
	Sandstone, shaly, dark red	400
	Conglomerate	25
	Sandstone, shaly, locally conglomeratic, pink to white in color	330
	Conglomerate, massive	25
	Sandstone, shaly, locally conglomeratic, pink	525
	Conglomerate, coarse, massive	10
	Sandstone, shaly, friable, varicolored, conglomeratic at many horizons	200
	Sandstone, conglomeratic at the base, more or less shaly above, with conglomerate at many horizons; petrified logs, 1 to 6 feet in diameter are numerous	1,120
	Unconformity	..
Mesaverde	Shale and sandstone with ironstone concretions	460
	Sandstone	10
	Shale with sandstone concretions, 1 foot 6 inches of coal near the top; contains at the base *Ficus* sp. type of *F. lanceolata* Heer; *Ficus* cf. *F. wardii* Kn.; *Ficus* n. sp. (3-nerved); *Viburnum* sp.; undescribed dicotyledons (U. S. G. S. locality No. 6028)	200
	Coal	2±
	Shale	150
	Coal	1
	Shale	3
	Coal	1
	Shale	7
	Coal	1
	Shale	5
	Sandstone, massive, gray	130
	Shale (Mancos), sandy in the upper part, with lenses and concretions of sandstone	..
		5,895+

The Mancos shale is well exposed west of the outcrop of the Mesaverde and does not differ in any essential manner from the Mancos of the Hagan section. As at Hagan, the lower part consists mainly of dark-colored shale and the upper part of sandy shale which weathers to a yel-

lowish brown color and contains fossiliferous concretions of impure limestone. No coal or carbonaceous shale was found below the sandstone that is here regarded as the base of the Mesaverde. The sandy shale is regarded as the transitional zone at the top of the Mancos, although it is quite possible it may be the equivalent in time of the lower part of the Mesaverde of other localities.

At the base of the measured section occurs a massive sandstone that appears to be at the same horizon as that at the base of the Mesaverde at Hagan. Five coal beds exposed in the mine entries, now abandoned, and several prospect openings were observed above this massive sandstone. The coals apparently hold the same position as those previously described from the Sloan and Hagan mines. Fossil plants were found at several horizons closely associated with the coal beds and several were collected principally from the sandstone and shale overlying the main coal bed. They are named as lot number 6028 in the accompanying section.

There is a series of shales and sandstones above the coal-bearing rocks containing ironstone concretions. These rocks may be the time equivalent of the rocks constituting the highest shaly member of the Mesaverde at Hagan. On them, as at Hagan, a conglomerate rests unconformably. It is the basal conglomerate of the colored rocks which are correlated in a general way with the Galisteo sandstone of the Cerrillos field. They contain great numbers of petrified logs, some of them very large. The state of preservation of most of them is poor and no specific determinations have been made. No identifiable fossils have been found in these colored rocks and their geologic age is not definitely known.

The coarse conglomerate which overlies the colored beds is composed principally of igneous material derived from the Ortiz Mountains. It consists of angular blocks of igneous rock varying in diameter from a few inches to several feet. The material is irregularly bedded and the beds dip eastward by about the same degree (30 degrees) as the underlying rocks. The thickness obtained by correcting for dip the distances measured across the strike in the upper part of the gulch, locally known as Devils Canyon, is about 3,000 feet, but this may be in excess of the actual thickness, for the bedding is too irregular to admit of accurate determinations of thickness. It is certain, however, that this conglomerate is many hundreds of feet in thickness. It is the same as the youngest conglomerate of the Hagan section that was described as lying unconformably on the Galisteo (?), Mesaverde, and Mancos formations.

CERRILLOS FIELD

The Cerrillos coal field is better known than those just described, mainly because of the productive mines which have been operated here

for many years. The coal-bearing rocks occupy a syncline between the Ortiz Mountains and Galisteo Creek and extend from the town of Galisteo westward for a distance of about 14 miles. The syncline is unsymmetrical and the rocks are warped and faulted in many places, but in general they dip from all directions toward the center of the syncline. The general geology of this field has been described by D. W. Johnson (83), and no space will be devoted to it in this paper farther than is necessary for an understanding of the age and structural relations of the Cretaceous and younger formations. The coal-bearing rocks are referred to the Mesaverde and are correlated with those of the Hagan, Tijeras, Rio Puerco, and Cabezon coal fields, as indicated in figure 2.

The principal coal beds of the upper part of the Mesaverde formation have been opened at Madrid and their thickness, character, and stratigraphic position are well known from mining operations. Coal has been mined from three beds, the lowest of which, known as the Cook and White coal bed, averages 3 feet in thickness. One hundred feet stratigraphically above this is the Peacock coal bed, averaging 1 foot 8 inches in thickness, and 22 feet higher is the White Ash coal, which normally contains coking bituminous coal, averaging 5 feet 6 inches in thickness. Near Madrid this White Ash coal has been changed to anthracite by the intrusion above the bed of a sheet of igneous rock 400 to 500 feet thick. The anthracite coal averages 3 feet in thickness. From data obtained in mining and kindly furnished to the writer by Mr. G. A. Kaseman, the following section of the coal-bearing rocks at Madrid has been constructed. This section probably furnishes the best standard with which to compare others measured in the Cerrillos coal field, although fossils are so scarce as to be of little assistance in correlating other sections with it.

Section of Rocks exposed at Madrid, New Mexico

	Feet	Inches
Intrusive igneous rock	..	..
Shale, containing fossil plants; *Geinitzia* sp	5±	..
Coal, White Ash bed	5	6
Shale and sandstone	22	..
Coal, Peacock bed	1	8
Shale and sandstone	8	..
Sandstone	20	..
Shale	20	..
Sandstone	20	..
Shale with thin seams of coal	2	..
Shale	6	..
Sandstone	20	..
Shale	3	..
Coal, Cook and White bed	3	..

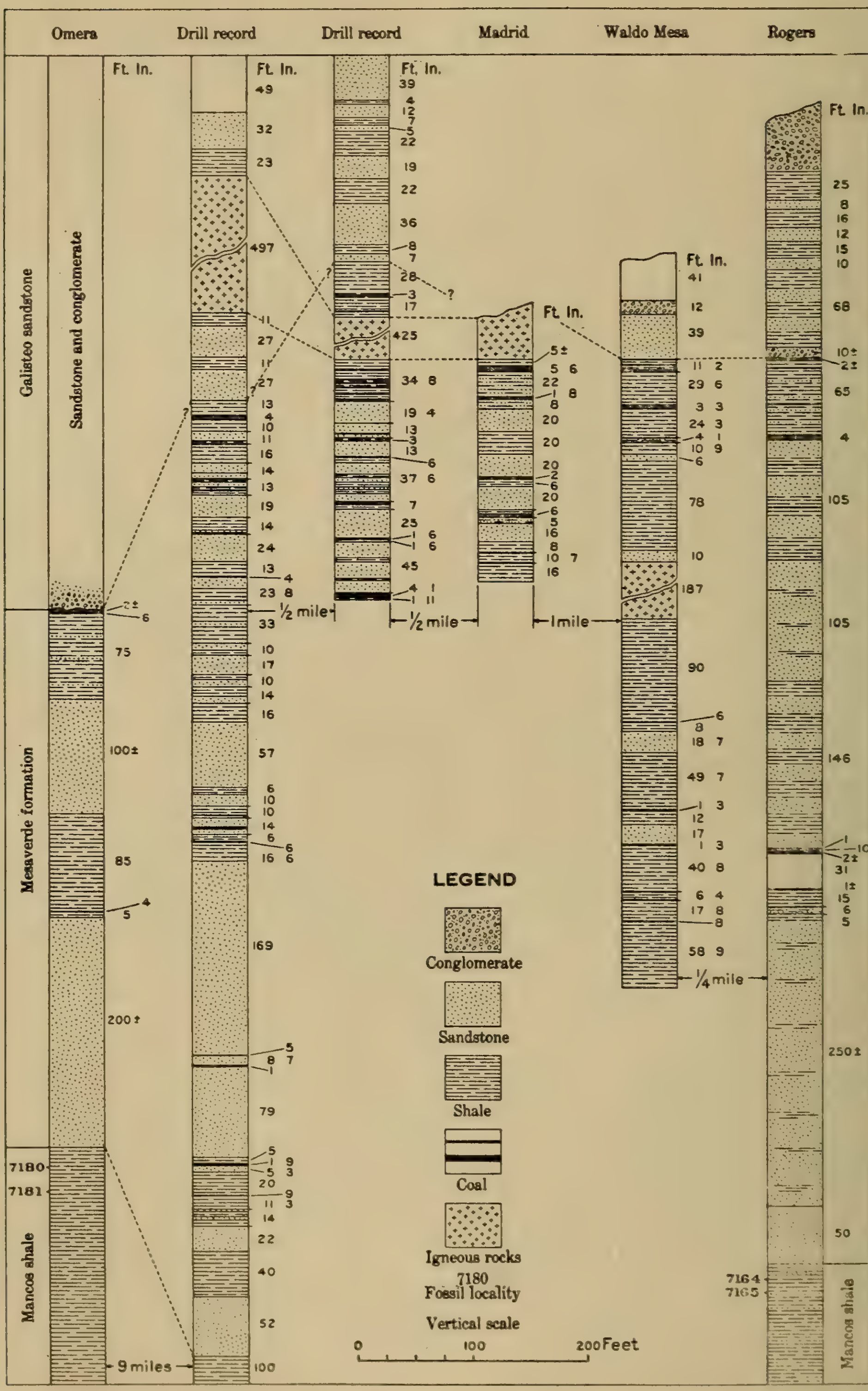


FIGURE 5.—*Geologic Sections and Drill Records in the Cerrillos Coal Field, New Mexico*

	Feet	Inches
Sandstone and shale	5	..
Sandstone	16	..
Shale	8	..
Coal	..	11
Shale	9	..
Coal	..	8
Shale	16	..
	191	9

Few fossils were found in the coal-bearing rocks at Madrid, although careful search was made for them. The shale beds overlying the coal in the mines near Madrid were searched, but at only one locality were fossil plants found in them. This is about a mile south of Madrid in the roof of a prospect opening in the White Ash coal bed, where conifers, identified as probably belonging to the genus *Geinitzia,* were found in shale above the coal. Where the Cook and White bed crosses Coal Gulch north of Madrid this coal bed is overlain by a massive sandstone in which are pinkish brown concretions of sandstone. In one of these concretions were found impressions of shells similar in appearance to some of the shells of marine origin that occur so abundantly in the sandstones at the base of the Mesaverde. The writer found no other shells above the coal beds near Madrid, but J. J. Stevenson (53, page 155) reports the occurrence of *Inoceramus* and *Ostrea* in the coal-bearing rocks.

The rocks at Madrid dip east about 15 degrees, and the mine entries have been driven down this dip under an intrusive sheet of igneous rock which forms the crest of a hill east of the town. Above this sheet and in a gulch about half a mile east of Madrid coal-bearing rocks are exposed near the mouth of an abandoned mine. The following section was measured by D. W. Johnson (83, page 107) at this locality and the section was later confirmed by the present writer. To the fossil plants reported by Doctor Johnson have been added those collected by the writer.

Section of Rocks measured at an abandoned Coal Mine one-half Mile East of Madrid, New Mexico

	Feet
Loose sand, upper part concealed	..
Intruded lava sheet	1
Sandstone, soft	8
Intruded lava sheet	3
Sandstone, soft	10
Sandstone, indurated, containing *Ficus rhamnoides* Kn.; *Ficus uncata* Lesq.; *Ficus speciosissima* ? Ward; *Ficus* sp. type *F. planicostata* Lesq.; *Palmocarpon commune* ? Lesq.; *Geonomites* sp.; *Quercus* ? sp.; *Aralia* ? sp.; (U. S. G. S. locality No. 6019)	9

	Feet
Shale, carbonaceous	10
Sandstone	6
Intruded lava sheet	10
Shale	4
Coal	2
Shale	3
	66+

The rocks of this section lie stratigraphically below the Galisteo sandstone and above the intrusive sheet of igneous rock that overlies the highest or White Ash coal bed at Madrid. The thickness of this intruded rock is shown in the accompanying records of drill-holes. A diamond drill prospect was made in the gulch a few hundred feet northeast of the old mine just mentioned and about 4,500 feet east of the principal opening at the outcrop of the White Ash coal bed. The drill penetrated something like 75 feet of rock that seems to belong to the Galisteo sandstone before it reached the coal-bearing rocks of the Mesaverde, and then encountered beds that seem to be equivalent to those of the section just given. After passing through the igneous rock, a group of coal beds was encountered that doubtless is the same as those opened at Madrid. The record is platted to scale in the third column of figure 5, on page 644.

A second drill-hole was put down 6,800 feet east of the outcrop of the White Ash coal bed. The drill reached a depth of 1,602 feet and penetrated not only the beds represented in the first record, but those of stratigraphic horizons considerably lower. The Galisteo sandstone occupies the surface in this region, but there is nothing in the record to indicate its thickness at this locality except the red or variegated color, which, however, may be caused by the metamorphic action of the intrusive igneous rock. Since no coal is known to occur in the Galisteo sandstone, it seems safe to draw the line of separation between this formation and the Mesaverde above the highest coal bed, as has been done in figure 5. This record shows the occurrence of three groups of coals. The highest group obviously corresponds with that represented by the beds underneath the sheet of intrusive rock in the first record and to those of the Madrid section. The two lower groups probably correspond in stratigraphic position to those described later near Omera farther east and to the lower coals near Rogers west of Madrid. The record is platted to scale in the second column of figure 5.

The dip of the rocks, which is 15 degrees east at Madrid, if unchanged would soon carry a given bed to a considerable depth. However, the dip no doubt lessens eastward toward the center of the basin, and it is

probable that the 1,602-foot hole extends entirely through the Mesaverde formation. The surface in the center is occupied by the Galisteo sandstone and younger rocks, but the underlying Mesaverde reappears from beneath them with opposite dip at the eastern extremity of the basin and was observed near the town of Galisteo, although no details of it were obtained there. However, at the southeastern extremity of the basin one of the Mesaverde coals has been developed at Omera mine. A section of the rocks exposed near this mine was measured. The dip is low, and the thicknesses given in the following section were obtained by pacing across the outcrop and correcting for dip. Hence the section is approximately correct, but it is presented only for the purpose of showing the relation of the Mesaverde formation to the underlying Mancos shale and to the overlying Galisteo sandstone.

Section of Rocks measured at Omera Mine, about 18 *Miles Southeast of Cerrillos, New Mexico*

		Feet	Inches
	Conglomerates base of Galisteo sandstone.		
	(Unconformity.)		
	Coal (Omera mine)........................	2±	
	Shale, carbonaceous..............................	0	6
	Shale, with layers of sandstone and cone-in-cone structure limestone (not continuously exposed)..	75	..
	Sandstone..	100±	..
Mesaverde	Shale, Carbonaceous in some places, with lenses and concretions of sandstone, and cone-in-cone structure limestone. Fossil plants at the base...	85	..
	Coal..	0	4
	Shale..	5	..
	Sandstone, massive, yellow; contains fossil shells..	200±	..
	Shale (Mancos) with a sandy transitional zone at the top. Concretions of fossiliferous limestone occur 100 to 150 feet from the top; containing *Exogyra ponderosa* Roemer ?; *Anomia* sp.; *Inoceramus sagensis* Owen ?; *Inoceramus* sp.; *Cucullœa* sp.; *Cyprimeria* sp.; *Volutoderma* ? sp.; *Nautilus* sp.; *Baculites* sp.; *Mortoniceras* sp. related to *M. delawarense* (Morton); *Placenticeras sancarlosense* Hyatt; *Placenticeras* sp.—very large specimens, apparently distinct from either of the foregoing (U. S. G. S. locality No. 7180). A few hundred feet lower in this shale the following fossils occur: *Crassatellites shumardi* Meek ?; *Mactra* sp.; *Gyrodes* sp.; *Volutoderma* ? sp.; *Actœon* ? sp. (U. S. G. S. locality No. 7181).....	..	..
		467	10

A comparison of this section with the 1,602-foot drill record seems to show that the lowest bed of coal, which is only 4 inches thick where the section was measured, but which is somewhat thicker in other places, corresponds in stratigraphic position with the lowest coal beds represented in that record; that the 100-foot sandstone of this section finds its counterpart in the 169-foot sandstone of the drill record, and that the coal developed in the Omera mine corresponds in position with the middle group of coal beds of the drill record and with the lowest developed coal of the Rogers section (see figure 5). If this correlation is correct it is evident that a large part of the Mesaverde formation as represented in other parts of the Cerrillos coal field is not present at Omera, and that the unconformity above the Omera coal represents an erosion interval of long duration.

As indicated in the foregoing section, the conglomerate of the Galisteo sandstone rests in some places directly on a coal bed. This bed varies considerably in thickness within short distances. In some places where shale intervenes between the coal and the overlying conglomeratic sandstone the coal bed is 4 to 5 feet thick. In other places where the conglomeratic sandstone rests on it the coal is thinner and in some localities is entirely replaced by the sandstone. This was found to be the case in the mine workings. J. H. Gardner states in his unpublished notes of the Omera mine that 560 feet down an old slope the coal suddenly disappears against a face of sandstone showing no evidence of faulting. He found that this disappearance was due to total erosion of the coal bed previous to the deposition of the sandstone. He also states that at one locality near Omera mine he found two coal beds separated by 9 feet of sandstone, the lower one 3 feet thick and the upper one 4 feet 6 inches thick. At one of the prospect entries, a few rods from the place where the Omera mine section given above was measured, the present writer observed two coal beds as follows:

Section of Rocks measured near Omera Mine

	Feet	Inches
Conglomerate with pebbles of several kinds of rock, including angular fragments of coal	..	..
Coal	0	2
Shale, sandy	2	6
Coal	4	2
Shale	..	..
	6	10

The conglomerate shown at the top of this section constitutes the base of the Galisteo sandstone. In it were found pebbles and boulders up to 6 inches or more in diameter, consisting of quartz, chert, sandstone, limestone, petrified wood, coal, etcetera. This formation is exposed continuously from Omera northward to Galisteo Creek and westward to Madrid.

Below the Mesaverde the Mancos shale occurs in characteristic development. Great numbers of fossils, especially cephalopods, occur in concretions of limestone near the top of the formation. The species collected here are named in the accompanying section. The thickness of the Mancos was estimated to be about the same as that given for it in the Rogers section, but no attempt was made to measure it. It dips gently toward the west and occupies the broad valley on either side of the Santa Fe Central Railroad. At the eastern side of this valley, about 3 miles east of the town of Galisteo, a few Benton fossils were collected. They are *Ostrea* sp., *Inoceramus fragilis* H. & M., *Prionotropis* sp., and undetermined casts of pelecypods and gastropods (United States Geological Survey locality number 7170).

About 2 miles south of the locality where these fossils were collected the Tres Hermanos sandstone was recognized, and between this sandstone and the Dakota the shale which contains the Gastropod zone at the localities described farther west. Below the Mancos shale is a hard conglomeratic sandstone which, on the basis of lithologic character and stratigraphic position, is referred to the Dakota, and under it are variegated sandstone and shale that probably are Morrison.

The rock formations above the Morrison in this eastern limb of the syncline correspond closely with those in the western limb, but below the Morrison there seems to be a difference. East of Omera a massive, cliff-making sandstone, about 100 feet thick, pink to red in color, occurs below the Morrison and lies unconformably on the deep red and purple sandstone and shale of the typical red bed formation of this region. This sandstone has the appearance of the Exeter sandstone (81, page 45) of eastern New Mexico and holds the same stratigraphic position. It was not recognized in the western limb of the syncline in the Cerrillos field, nor farther southwest in the Hagan and Tijeras fields, although it may be represented west of the Rio Puerco by a red cliff-making sandstone which occurs below the Morrison. Below this sandstone east of Omera occur red rocks similar to the Manzano red beds that underlie the Morrison west of the Cerrillos field.

The line of outcrop of the coal beds extends from Omera in a northwesterly direction and seems to pass around the northern base of the

Ortiz Mountains to the coal in the vicinity of Madrid, but in the intervening space the coal is covered with debris from the mountains. North of Omera the coal beds were displaced by the intrusion of the igneous rock of Cerro Pelon, which rests on the basal sandstone of the Mesaverde at its southern end and on Mancos shale farther north. This shale and basal sandstone were observed underlying the Galisteo sandstone north of Cerro Pelon in the vicinity of the town of Galisteo, but no indication was found that any coal occurs there. It seems probable that the erosion which preceded the formation of the Galisteo sandstone removed all rocks that may have existed above the basal sandstone of the Mesaverde in the vicinity of Galisteo. Little was seen of the Mesaverde or of the older rocks between Galisteo and Cerrillos. They are covered for the most part by younger rocks, but near Cerrillos the Mancos and Mesaverde reappear in vertical position upturned by the intrusion of the igneous rocks of the mountains north of this town.

West of Cerrillos the rocks dip steeply to the south and Galisteo Creek flows in a gorge cut along the strike partly in the Mancos shale and partly in the basal sandstone of the Mesaverde formation. About one and one-half miles west of Cerrillos the rocks are well exposed south of the stream, and a section was examined carefully for the purpose of locating the coal beds which have been developed at Rogers, a coal-mining camp west of Madrid, now abandoned. At the horizon where the main coal beds should occur coal was found, but the beds are thin, possibly due to crushing at the time the rocks were upturned. Otherwise the section at this locality does not differ materially from the Rogers section which follows, except that the base of the Galisteo sandstone is more coarsely conglomeratic than it is at Rogers. It consists here of hard quartzose sandstone containing pebbles principally of quartz and chert up to an inch or more in diameter.

Fossil plants were found at this locality at a horizon about 325 feet above the top of the basal sandstone of the Mesaverde. They occur in shale in a railroad cut on the branch line from Waldo to Madrid. They are as follows:

Fossil Leaves collected in a Railroad Cut one and one-half Miles West of Cerrillos

(United States Geological Survey locality number 6021)

Brachyphyllum sp.
Celastrus n. sp.
Ficus speciosissima Ward
Ficus lanceolata Heer
Ficus n. sp. (3-nerved)

South and west of the locality just described on Galisteo Creek the rock formations are well exposed and were traced to Rogers, an abandoned coal camp situated on the western limb of the syncline. The rocks strike nearly north and south and dip 9 degrees east. A section was measured by tapeline from the old Rogers mine westward across the strike of the upturned rocks to a point at the base of the Cretaceous about a mile south of Galisteo Creek. This section may be combined with the Galisteo Canyon section of the Manzano group published by the writer several years ago (110 B, page 18).

Section of Rocks measured near the old Rogers Mine, two Miles southwest of Cerrillos, New Mexico

		Feet	Inches
	Conglomerate (Recent).		
Galisteo	Shale, sandy	25	
	Sandstone, yellow	8	
	Shale, sandy, yellow	16	
	Sandstone, massive	12	
	Shale, sandy, light-colored	15	
	Sandstone, massive, gray	10	
	Shale and sandstone in alternating layers	68	
	Sandstone, massive, coarse-grained, friable, loose-textured to quartzose; locally conglomeratic; variable in thickness and character; contains fossil plants; *Abietites dubius* (?) Lesq.; *Geonomites* sp.; *Dryopteris* ? sp.	10±	
	(Unconformity by erosion.)		
Mesaverde	Coal, thickness irregular, due to erosion; absent in some places	2±	
	Sandstone, shale, and thin beds of coal in alternating layers; contains fossil leaves, conifers and *Nelumbo intermedia* ? Kn.	65	
	Coal (Rogers opening)	4	
	Shale and sandstone; the shale carbonaceous in some places with thin seams of coal	105	
	Sandstone in massive layers separated by thin beds of shale; forms the crest of a ridge	105	
	Sandstone and shale in alternating layers; contains concretions of brown sandstone	146	
	Coal	1	
	Shale (0 to 10 feet)	5	
	Coal	2±	
	Covered	31	
	Coal, dirty	1±	
	Shale with yellowish limestone concretions, containing *Ostrea* sp. related to *O. soleniscus* Meek	15	
	Coal	0	6
	Sandstone and shale	5	
	Coal	0	6

		Feet	Inches
Mesaverde	Shale	5	
	Sandstone, principally massive, light gray, friable in some places with brown flinty concretions. Thickness varies from place to place, but the lower 50 feet or more forms a prominent cliff—the basal sandstone of the Mesaverde—and contains: *Halymenites major* Lesq.; *Mactra* sp. related to *M. alta* M. and H.; and several gastropods and other shells similar to those found below the basal sandstone	300±	
Mancos	Shale with thin layers of gray sandstone; constitutes the transition zone from the shale below to the base of the Mesaverde; contains *Ostrea elegantula* Newberry?; *Anomia* sp.; *Inoceramus* sp. related to *I. proximus* Tuomey; *Inoceramus* sp. related to *I. barabini* Morton; *Cucullœa* sp.; *Cardium* sp.; *Cyprimeria* sp.; *Legumen* ? sp.; *Corbula* sp.; *Mactra* ? sp.; *Anatina* sp.; *Dentalium* sp.; *Turritella galisteoensis* Johnson; *Volutomorpha* sp.; *Volutoderma* ? sp.; *Nautilus dekayi Morton* ?; *Scaphites* sp. related to *S. hippocrepis* De Kay; *Baculites* sp.; *Placenticeras sancarlosense* Hyatt; *Placenticeras planum* Hyatt (U. S. G. S. localities Nos. 7164 and 7165)	150±	
	Shale, dark-colored, with fossiliferous concretions of limestone near the top and near the bottom	2,100	
	Sandstone (Tres Hermanos), hard, quartzose in thin, irregular layers; weathers yellowish brown; contains shells, numerous worm borings, and indefinite markings of various kinds; also *Halymenites major* Lesq.; *Pinna petrina* White ?; *Pecten* sp.; *Gyrodes* sp.; *Turritella* sp. (U. S. G. S. locality No. 7168)	20	
	Shale, dark-colored, with dark brown concretions of impure limestone (Gastropod zone) and a stratum of "crinkly" sandstone one foot thick near the middle	75	
	Conglomerate containing pebbles of quartz and chert up to an inch in diameter	2	
	Shale, carbonaceous, with coal a few inches thick near the top	5	
	Sandstone (Dakota), hard, quartzose, massive, cross-bedded, locally conglomeratic near the base	50±	
	Sandstone, white, more evenly bedded than the hard sandstone overlying it	40±	
	Shale and sandstone, variegated in color	80	
	Conglomerate, cross-bedded, massive; pebbles an inch or more in diameter	10	
	Shale, variegated, and sandstone (Morrison), thickness estimated	200	
		3,689	

The variegated sandstone and shale at the base of the section has been referred to the Morrison on lithologic and stratigraphic grounds. No fossils have been found in it in this region. The lower part, 200 feet or more in thickness, consists of soft shale and friable sandstone of many shades of color. This character has been noted in so many places that it has come to be regarded as more or less diagnostic of the Morrison formation. Above these softer beds is a coarse conglomerate 10 feet thick overlain by 80 feet of variegated sandstone and shale. Were it not for the color of the beds above it this conglomerate might be regarded as the base of the Dakota. However, although conglomerate is rare in the Morrison the reference of the 10-foot conglomerate to this formation seems inevitable; also the overlying thin-bedded sandstone, although white, probably belongs in the Morrison. Between it and the overlying conglomerate, which is here referred to the Dakota, there is an uneven line of separation more or less conspicuous which may mark an unconformity. The writer has formerly shown (112, page 18) that in the Galisteo Canyon the Morrison apparently lies unconformably on the Yeso formation. It seems probable therefore that the Morrison in this region is separated in time from both underlying and overlying formations.

Above the rocks here referred to the Morrison is a sandstone about 50 feet thick, conglomeratic near the base and otherwise similar in character and appearance to the Dakota sandstone throughout the southern Rocky Mountain region. No fossils were found in it, and its reference to the Dakota is based on its lithology and stratigraphic position.

Carbonaceous shale in which coal occurs in some places was found above the Dakota sandstone. The shale and coal are both irregular in thickness and character. The coal was observed in several places and found to vary in thickness from a mere film to about 6 inches. There is a conglomerate above the coal which also varies in thickness and character and is absent in some places. Apparently this carbonaceous shale, coal, and conglomerate belong in the Mancos shale formation and are not to be included in the Dakota. The only place at this locality where a line of separation can rationally be drawn between the Dakota sandstone and the Mancos shale is at the base of the carbonaceous shale, where there is an abrupt change from the shale to the quartzose sandstone below it. On the other hand, there is a tendency on the part of some observers of Rocky Mountain geology to call any coal near this horizon "Dakota coal," and it is probable that although this coal in the Galisteo region clearly lies above the base of the Mancos shale it may be the equivalent in age of some of the so-called Dakota coal of the southern Rocky Mountain region. An attempt was made to find the coal at other localities in the Cerrillos

and Hagan fields, but neither the coal nor the conglomerate overlying it was found. It is evident that both the coal-bearing shale and the conglomerate are local in occurrence and of very restricted distribution.

The shale overlying the conglomerate is ordinary dark-colored clay shale of marine origin. A few shells of the genus Inoceramus were found near the base. A stratum of sandstone and a zone of concretions of impure limestone occur midway of the shale and contain fossils, but none were collected. The limestone concretions probably represent the Gastropod zone of the Rio Puerco field.

The Tres Hermanos sandstone, at this locality only 20 feet thick, overlies the shale containing the Gastropod zone. It is very resistant and forms a hogback more prominent than that of the Dakota. It consists of thin irregular layers of sandstone an inch or less in thickness, on the faces of which are ripple-marks, worm tracks, and markings of many kinds. The sandy layers are separated in some places by films of shale. A few imperfect casts of gastropods were found in this sandstone and impressions supposed to be *Halymenites major* are abundant in some places. The species named in the accompanying section (number 7168) were found in blocks of sandstone at the base of a cliff of the Tres Hermanos sandstone where the section was measured. The sandstone is unlike any other rocks near it and has a peculiar appearance that makes its recognition easy.

At a horizon estimated to be 100 feet stratigraphically above the Tres Hermanos sandstone there is a small ridge formed by a limestone about 3 feet thick which presumably represents the Greenhorn limestone. It contains great numbers of *Inoceramus labiatus* Schloth. At a higher horizon, estimated as 500 feet above the base of the Cretaceous, *Inoceramus labiatus* Schloth. and *Prionocyclus wyomingensis* Meek were found in a limestone having a strong odor of petroleum. These fossils are among those collected by D. W. Johnson at the town of Cerrillos near the smelter and determined by him as belonging to the Colorado fauna (83, page 103). They are as follows:

Fossils collected near the Smelter at Cerrillos, New Mexico

Ostrea lugubris Conrad
Inoceramus labiatus Schlotheim
" *dimidius* White
" *fragilis* H. & M.
" *strongi* Johnson
Scaphites warreni M. & H.
Prionocyclus macombi Meek
" *wyomingensis* Meek
Prionocyclus sp. nov.
Prionotropis woolgari Mantell
Rostellites dalli var. *wellsi* Johnson
" *ambigua* Stanton ?
Acmea cerrillosensis Johnson
Scurria ? coniformis Johnson
Beryx sp. undet.

The top of the Mancos shale of this section is particularly rich in fossils. In the upper 200 feet of the shale were found the species named in the section measured near Rogers mine (numbers 7164 and 7165). Another collection reported beyond was made at approximately the same horizon north of Galisteo Creek. In commenting on these fossils Doctor Stanton says: "The horizon is believed to be a short distance above the Austin chalk and the Niobrara limestone—that is, in the lower part of the Montana group."

The base of the Mesaverde formation in the Cerrillos field consists of a massive cliff-making sandstone overlain by other sandstones which are softer and somewhat shaly in places. These sandstones form the surface of a dip slope that is unevenly eroded and their measured thickness is open to question. The measurement of 300 feet, shown in the accompanying section, was obtained by measuring with tapeline across the strike of rocks dipping only 5 to 8 degrees and computing the thickness from the dip and horizontal distance measured. It is not certain that the dip is constant nor that no faults occur. No coal was found in this lower 300 feet of the Mesaverde, but at neighboring localities thin beds of coal occur in rocks that probably are equivalent to these lowest rocks of the formation. The sandstone contains large yellow concretions, consisting of calcareous sandstone, in which marine fossils were found. Some shale occurs, but it seems to be very subordinate in amount. Apparently this 300± feet of sandstone corresponds to the part of the 1,602-foot drill record between the lowest shale and the top of the 169-foot sandstone. This drill record shows the occurrence of the thin beds of coal supposed to occur in the lower part of the Rogers section, but which were not found where the section was measured. The Mesaverde formation at Rogers contains two groups of developed coal beds, the upper one probably equivalent to the group described at Madrid and the lower one to the coals at Omera and to the middle group shown in the 1,602-foot drill record. These relations are best shown in figure 5.

No fossil plants were found in the Mesaverde near Rogers, but oyster shells, identified as *Ostrea* sp. related to *O. soleniscus* Meek, were found about half a mile south of the line along which the section was measured. They occur in yellow concretions similar to those in the basal sandstone of the Mesaverde which yielded Gastropods and other marine fossils indicated in the section. They occur above a thin bed of coal about 50 feet stratigraphically above the lowest coal observed at this locality. The oyster shells are large and no complete ones could be found, but fragments were obtained an inch or more in thickness and 10 inches long.

There is good evidence at Rogers of an unconformity between the Mesa-

verde and the overlying Galisteo sandstone. A coal bed occurs about 65 feet stratigraphically above the coal at the old Rogers opening. This coal is 3 feet or more in thickness in some places and in other places is entirely absent. This variation in thickness is due to irregularities of the upper surface obviously caused by erosion. On this unevenly eroded surface lies a light-colored, coarse-grained sandstone that is locally conglomeratic. No coal nor dark-colored shale, such as is associated with the coal lower in the section, was observed above this sandstone. The rocks above it are pink, blue, green, etcetera, and gradually merge into the undoubted Galisteo sandstone which is typically developed farther to the east.

A few poorly preserved fossil leaves named in the section were found in this basal member of the Galisteo at Rogers, but they are not of a character to render possible the determination of the age of the rocks containing them.

A diamond drill prospect was made on Waldo Mesa about half a mile south of the old Rogers mine. It has been platted to scale in figure 5, on page 644. The drill passed through a group of coal beds that is obviously the same as the upper group of the Rogers section and then penetrated 187 feet of igneous rock. This rock is a part of a great intrusive sheet that is very prominent farther south, but which does not extend northward to the Rogers mine. Apparently it is not the intrusive sheet of the two drill records previously given, but one intruded at a lower horizon. It underlies the coal beds at Madrid, as is well shown in figure 5 of Doctor Johnson's paper (83, page 37).

A second group of coal beds was penetrated by the drill below the sheet of igneous rock, and these seem to be the same as the lower group of developed coals of the Rogers section and the middle group of the 1,602-foot drill record. This correlation of the groups of coal beds at the several localities described seems relatively simple, but it is not so easy to correlate the individual beds. The upper group of the Waldo Mesa drill record corresponds in a general way with the group of coals developed at Madrid, but for some unknown reason there are fewer coal beds than at Madrid. It is possible, on the one hand, that the Waldo Mesa coal beds represent those near the horizon of the Cook and White coal of the Madrid section, and that the higher beds were eroded away previous to the deposition of the Galisteo sandstone at the Waldo mesa locality. On the other hand, it seems probable that the Waldo mesa coals may correspond in position with the higher ones of the Madrid section, and that the lower beds of Waldo mesa may have been destroyed by the intrusion of the igneous rock.

The rock formations near the base of the Cretaceous are well exposed in Canyon del Yeso, about 2 miles north of Galisteo Creek, where the following section of them was measured. Fossils were collected from these formations and included in the descriptive section. That part of the Mancos shale lying stratigraphically above this section was found to be fossiliferous in many places, but it does not lend itself readily to measurement.

Section of Rocks measured in Canyon del Yeso about 2 Miles North of Galisteo Creek

	Feet
Limestone and shale in alternating layers, containing *Inoceramus labiatus* Schloth. (horizon of Greenhorn limestone)	15
Shale, containing *Prionotropis* sp.	100±
Sandstone (Tres Hermanos), hard, quartzose, with sparkling sand grains, brown to yellow, in thin irregular layers with numerous worm borings and various indefinite markings. In the lower 10 feet the layers of sandstone are separated by thin layers of shale	25
Sandstone, containing *Inoceramus* sp. and *Pinna* sp.	10
Shale (Gastropod zone), dark-colored, with concretions of earthy limestone 20 feet from the top. Some of the concretions are fossiliferous and weather to a rusty yellow powder around the fossils, rendering specific idenfification difficult. From these concretions were obtained *Ostrea* sp.; *Exogyra columbella* Meek; *Plicatula* sp.; *Lima* sp.; *Pinna* sp.; *Anchura* sp. (U. S. G. S. locality No. 3536)	70
Sandstone (Dakota), conglomeratic at the base	40
Shale, sandy, near the top	10
Sandstone, coarse-grained, cross-bedded, white	70
Sandstone and shale, variegated (Morrison)	

An effort was made to recognize in this section the several zones described from the lower part of the Rogers section located 3 miles farther south. The sandstone and shale, here referred to the Morrison, is similar lithologically to the variegated beds below the 10-foot conglomerate in the Morrison of the Rogers section. The 40-foot conglomerate sandstone is referred to the Dakota and the lower sandstone, 70 feet thick, is probably also Dakota, although it may be equivalent to the beds of the Rogers section lying below the conglomeratic Dakota and there referred with some doubt to the Morrison because it differed lithologically from the overlying Dakota. The rocks above the Dakota in Canyon del Yeso are the same as those similarly situated in the Rogers section. The 70-foot shale corresponds in position to the shale containing the Gastropod zone and the 35 feet of sandstone above it to the Tres Hermanos sandstone of the Rio Puerco field. The Greenhorn limestone horizon was recognized by its characteristic fossil, *Inoceramus labiatus*. Two hundred feet or

more stratigraphically higher in the section there is a zone about 50 feet thick containing large concretions of limestone, many of which are fossiliferous. These concretions contain *Inoceramus fragilis* H. and M., *Volutoderma* sp., *Prionotropis* sp., and *Pachydiscus* n. sp.

Some of the ammonites are very large. *Pachydiscus,* the largest one found, probably measured between 2 and 3 feet across when complete, but only a small part of it was obtained. About 100 feet stratigraphically above the concretions just mentioned some thin layers of limestone in the shale yielded *Ostrea* sp., *Inoceramus fragilis* H. and M., *Inoceramus* sp. related to *I. dimidius* White, *Scaphites warreni* M. and H., and *Prionotropis* sp. (United States Geological Survey locality number 3542).

East of the last named locality the surface is nearly level and the shale is more or less covered with soil. However, in a small ridge about 1,800 feet east of this locality and at a horizon somewhat higher a few poorly preserved specimens of *Inoceramus* were found, which are either *Inoceramus deformis* Meek or a variety closely resembling it. The fossils suggest correlation with the Niobrara formation and also with the Punta de la Mesa sandstone, but the lithology does not admit of either correlation. About a mile farther east and at a still higher horizon the shale contains numerous concretions of limestone which are very fossiliferous. This probably represents the zone of concretions near the top of the Mancos shale west of Rogers that yielded the fossils named in the Rogers section (numbers 7164 and 7165). The following species were collected from these concretions:

Fossils collected about 5 Miles Northwest of Cerrillos, New Mexico

(United States Geological Survey localities numbers 3532 and 7166)

Ostrea sp.	*Liopistha undata* M. & H.
Exogyra ponderosa Roemer	*Corbula* sp.
Inoceramus sagensis Owen	*Mactra* ? sp.
" *irregularis* Johnson	*Gyrodes* sp.
" sp.	*Anchura* sp.
Leda sp.	*Nautilus dekayi* Morton
Cucullæa ? sp.	*Baculites asper* Morton?
Nucula sp.	*Hamites* sp.
Cardium sp.	*Placenticeras planum* Hyatt
Astarte sp.	" *sancarlosense* Hyatt
Crassatellites shumardi Meek	*Placenticeras* sp.
Cyprimeria sp.	*Stantonoceras pseudocostatus* Johnson

In commenting on the age relations of these fossils, Stanton states that they are about the same as those from the top of the Mancos in the Rogers section, of which he says:

"The fauna is related to the Gulf and Atlantic Coast Cretaceous faunas more closely than to those of the Rocky Mountain region. Its horizon is believed to be a short distance above that of the Austin chalk and the Niobrara limestone—that is, in the lower part of the Montana group."

This locality is near the place at which Johnson (83, page 105) collected the fossils described by him as Pierre, but inasmuch as no sandstone was found by the writer at this locality it is probable that the fossils are slightly lower than Johnson's in the section. His description is as follows:

"Two miles southwest of Santa Rosa Mountain, where the main wagon road leaves the basalt-capped mesa for the valley below, there are exposed in the valley at the foot of the mesa fossiliferous shales and sandstones. The exposure is not large, but a small arroyo has removed some of the looser shales, leaving still in place the calcareous nodules in which the fossils are most abundant.

"The following species were collected at this locality:

Ostrea congesta Conrad ?
Protocardia rara E. & S. ?
Astarte evansi H. & M.
Nucula subplana M. & H.
Solen cuneatus Gabb. ?
Lingula subspatulata H. & M.
Tritorium kanabense Stanton
Natica sp. undet.
Baculites anceps Lamarck
Heliococeras pariense White ?
Beryx sp. undet.
Arca madridensis Johnson ?
Cyprimoria ? *sulcata* Johnson
Turritella galisteoensis Johnson
Admetopsis ? *elevata* Johnson"

Bibliography and Notes

The following list contains the principal publications in which information is to be found relative to the rock formations of the several coal fields described in this paper, and includes some outside publications which have had a direct influence on investigations in these fields. The publications are arranged in chronological order and brief notes are attached, calling attention to the character of the information relating to the formations here described. These notes are intended to serve the double purpose of pointing out the data presented in each paper and of placing them in such a way that they will form a history of investigation. Since this paper is not primarily concerned with the economic resources of the coal fields, little attention is given to purely economic reports such as mineral resources. However, considerable geologic information is given in some of the economic papers and many of them are included in the list. There are many papers that make only casual reference to the New Mexico coal fields without giving any definite information. Most of these have been omitted. In order that the papers may be

found readily, the form of reference used in the bibliographies of the United States Geological Survey has been followed.

No. Date.

1. 1848. Abert, J. W.: Report on examination of New Mexico in the years 1846-1847.

Report Sec. War, 30th Cong., 1st sess., Senate Doc. No. 23, pp. 3-130, 24 plates, map (Washington, 1848); 30th Cong., 1st sess., Ex. Doc. No. 41, pp. 417-546. Washington, 1848.

(P. 37) Coal was found in the Cerrillos field and on the Rio Puerco. (P. 547) From the Rio Puerco coal beds (at Poblozon) he collected fossils which Bailey determined as Cretaceous.

2. 1848. Bailey, J. W.: Notes concerning the minerals and fossils collected by Lieut. J. W. Abert while engaged in the geographical examination of New Mexico.

Report Sec. War, 30th Cong., 1st sess., Senate Ex. Doc. No. 23, pp. 131-132, 3 plates (Washington, 1848); 30th Cong., 1st sess., Ex. Doc. No. 41, pp. 547-548. Washington, 1848.

Reviewed, Am. Jour. Sci., 2d series, vol. 6, pp. 389-392. 1848.

The Cretaceous fossils collected by Abert at Poblozon, in the Rio Puerco coal field, New Mexico, are described. (Poblozon is a few miles north of San Ygnacio.)

3. 1848. Wislizenus, A.: Memoir of a tour to northern Mexico, connected with Doniphan's expedition in 1846 and 1847, 141 pages, 3 maps. Washington, 1848.

Geographisches Jahrbuch von Dr. Berghaus (Gotha). 1850.

Abstract, Am. Jour. Sci., 2d series, vol. 6, pp. 376-386. 1848.

For the occurrence of coal in the Rio Puerco coal field see accompanying map.

4. 1850. Simpson, James H.: Journal of a military reconnaissance from Santa Fe, New Mexico, to the Navajo country.

Reports of the Secretary of War, with reconnaissance of routes from San Antonio to El Paso, by Johnson and others (etc.), 31st Cong., 1st sess., Senate Ex. Doc. No. 64, pp. 146-148. Washington, 1850.

(Pp. 72 and 146-147) Coal was found in 1849 on the Rio Puerco north of Cabezon and at several localities farther west in northwestern New Mexico.

5. 1853. Hitchcock, Edward: Notes on the specimens of rocks and minerals collected.

Exploration of the Red River of Louisiana in 1852, by Marcy, pp. 163-178. Washington, 1853. 32d Cong., 2d sess., Senate Doc. No. 54.

(Another edition, pp. 140-155. Washington, 1854.)

(P. 165) The paper contains a review of the occurrences of coal previously described.

6. 1855. Marcou, Jules: Résumé of a geological reconnaissance, extending from Napoleon, at the junction of the Arkansas with the Mississippi, to the Pueblo de Los Angeles in California.

No. Date.

Report of exploration for railway route to the Pacific Ocean, near 35th parallel, by Whipple, vol. IV, pp. 40-48, 8° (Washington, 1855), House Doc. 129.

(Also) Explorations for a railway route from the Mississippi to the Pacific, vol. III, part IV, route near the 35th parallel, explored by Whipple. Report of the geology of the route, by Blake, pp. 165-175, plate, 4° (33d Cong., 2d sess., House Ex. Doc. No. 91; also Senate Ex. Doc. No. 78. Washington, 1856).

(P. 45) The Cretaceous coal beds near Tijeras (Tigeras of Marcou) seem to be confused with Carboniferous coal beds which occur in the Sandia Mountains near by. (P. 46) The Cretaceous rocks underlying the coal beds near Galisteo are described.

7. 1856. Blake, William P.: Report on the geology of the route.

Explorations for a railroad route from the Mississippi to the Pacific, vol. 3, part IV; route near the 35th parallel explored by Whipple, 116 pages, maps, plates, 4°, 33d Cong., 2d sess., House Ex. Doc. No. 91. Washington, 1856. Includes report on fossils by J. Hall, pp. 99-105, plates.

(P. 34) The Cretaceous age of the rocks examined by Abert at Poblozon on the Rio Puerco is accepted and Whipple and Marcou are quoted as reporting coal on the Rio Puerco and near Laguna and Cebolleta (p. 36) in rocks which are regarded as Cretaceous.

8. 1860. Blake, William P.: Observations on the geology of the Rocky Mountain chain in the vicinity of Santa Fe, New Mexico (abstract).

Am. Assoc., Proc., vol. 13, pp. 314-319. 1860.

(P. 315) The anthracite coal found in 1857 near Cerrillos is described.

9. 1861. Blake, William P.: Observations on the mineral resources of the Rocky Mountain chain near Santa Fe, and the probable extent southward of the Rocky Mountain gold field.

Boston Soc. Nat. Hist., Proc., vol. 7, pp. 64-70. 1861.

The occurrence of anthracite coal near Cerrillos examined in 1857 is described. In the same connection the author refers to the Carboniferous coal beds at Santa Fe.

10. 1861. Newberry, John S.: Geological report.

Report on the Colorado River of the West, explored in 1857 and 1858 by Lieut. Joseph C. Ives, part III, 154 pages, 6 plates, 4° (36th Cong., 1st sess., Senate Ex. Doc. —). Washington, 1861.

Abstract, Am. Jour. Sci., 2d series, vol. 33, pp. 394-403. 1861.

Some of the coal near Moqui is described as Jurassic (p. 85) and some as Cretaceous, the latter associated with fossil plants similar to those of the Dakota of Kansas and Nebraska. The Cretaceous coal of this author occurs also both east and west of Fort Defiance (in the San Juan coal basin). (P. 100) Carboniferous fossils were obtained from the coal measures at Santa

No. Date.

Fe and samples of the anthracite from near Cerrillos were obtained, but that locality was not visited.

11. 1865. Owen, R. E., and Cox, E. T.: Report on the mines of New Mexico, 60 pages. Washington, 1865.

Abstract, Am. Jour. Sci., 2d series, vol. 40, pp. 391-392 (½ p.). 1865.

Anthracite coal, regarded as Carboniferous, is reported at Placer Mountain (Cerrillos field) (pp. 23 and 40), and bituminous coal is reported on the Rio Puerco (p. 24).

12. 1868. Hayden, F. V.: Rocky Mountain coal beds.

Am. Jour. Sci., 2d series, vol. 45, pp. 101-102. 1868.

(P. 102) The author refers briefly to the coal beds in New Mexico and includes them with his Tertiary lignites.

13. 1868. Le Conte, John L.: Notes on the geology of the survey for the extension of the Union Pacific Railway from the Smoky Hill River, Kansas, to the Rio Grande, 76 pages, 8°. Philadelphia, 1868.

(P. 34) Coal is reported near Tijeras, New Mexico; at Tierra Amarilla, about 120 miles northwest of Santa Fe (p. 36); in Rio Puerco Valley (p. 41); and (pp. 38-40) the anthracite near Cerrillos is described and also the occurrence of fossil leaves in the rocks associated with it. The coal is referred to the Cretaceous and said to be older than the Laramie of the Denver Basin ("Marshall formation").

14. 1868. Le Conte, John L.: Cretaceous coals in New Mexico.

Am. Jour. Sci., 2d ser., vol. 45, p. 136 (½ p.). 1868.

The coal beds near Cerrillos are referred to and correlated with coal beds described by Newberry in the lower part of the Cretaceous of northwestern New Mexico.

15. 1869. Hayden, F. V.: Preliminary report for 1869 (see 3d Annual Report, 1873).

16. 1870. Raymond, Rossiter W.: Statistics of mines and mining.

Report, 41st Cong., 2d sess., H. R. Ex. Doc. No. 207, pp. 1-805. Washington, 1870.

The coal beds at "Old Placer Mountain;" also on the Rio Puerco, near Fort Wingate, and elsewhere are described (p. 417).

17. 1871. Newberry, John S. On the age of some western lignites.

New York Lyceum Nat. Hist., Proc., vol. 1, p. 252 (½ p.). 1871.

The coal beds near Cerrillos are referred to the Cretaceous.

18. 1872. Lesquereux, Leo: An enumeration, with descriptions, of some Tertiary fossil plants from specimens procured in the explorations of Dr. F. V. Hayden in 1870.

United States geological survey of Montana and portions of adjacent Territories, preliminary report, F. V. Hayden in charge, 5th Report of progress (Supplement), pp. 1-22. 1872.

No. Date.

Fossil leaves collected from the coal measures near Cerrillos are included among the "Tertiary plants:" *Populus balsomoides* Göpp.; *Quercus platanea* (?) Heer; *Ficus tiliœfolia* Heer; *Platanus guillelmœ* Heer; *Cinnamomum mississippiense* Lesq.; *Magnolia; Carpolithes spirales* Lesq.; *Carpolithes compositus* Lesq.; *Carpolithes mexicanus* Lesq. [Inasmuch as the coal-bearing rocks now known to be Mesaverde were not distinguished by Lesquereux from the younger rocks of probable Tertiary age, and inasmuch as both formations are plant-bearing, it is possible that these fossils may have come from the Tertiary as their names suggest, rather than from the coal-measures, as he supposed.]

19. 1873. Hayden, F. V.: Geological report. Report of the United States geological survey of Colorado and New Mexico, Washington, 1869, under F. V. Hayden, 3d Annual Report, pp. 103-199. Washington, 1873.

Abstracts, Am. Nat., vol. 4, pp. 119-121, 1871; Am. Jour. Sci., 2d series, vol. 49, pp. 258-263, 1869.

(The 3d Annual Report was published as a preliminary field report in 1869.)

The coal beds near Cerrillos are described (p. 167). The coal-bearing rocks containing "abundant impressions of deciduous leaves" are referred to the Tertiary, and the Galisteo sandstone is correlated with the Monument Creek formation of the Denver region. The Galisteo is described as lying conformably on the coal measures. (P. 98) An analysis is given of the "Placer" anthracite.

20. 1873. Clark, R. Neilson: The Tertiary coal beds of Canyon City, Colorado.

Am. Inst. Mining Eng., Trans., vol. 1, pp. 293-296, plate. 1873.

The occurrence of coal near Cerrillos, New Mexico, is referred to, and E. T. Cox (p. 298) mentions his former visit to the anthracite mine.

21. 1873. Lesquereux, Leo: Lignitic formations and fossil flora.

United States geological and geographical survey of the Territories embracing portions of Montana, Idaho, Wyoming, and Utah, F. V. Hayden in charge, 6th Annual Report (for 1872), pp. 317-427. Washington, 1873.

Abstracts, Am. Jour. Sci., 3d series, vol. 6, pp. 441-450; Am. Nat., vol. 8, pp. 217-218 (1/5 p.). 1874.

(P. 363) The author refers to coal measures in Tijeras Canyon, and near San Felipe (probably in the Tijeras and Hagan coal fields); also at other localities farther west. The Placer Mountain coal beds (Cerrillos field) are correlated with those at Raton, New Mexico, and with those of the Canyon City field in Colorado.

22. 1874. Cope, Edward D.: On the mutual relations of the Cretaceous and Tertiary formations.

No. Date.

United States geological and geographical survey of the Territories, embracing Colorado, F. V. Hayden in charge (7th) annual report (for 1873), pp. 427-444, plates. Washington, 1874.

The literature of "The Fort Union or Lignitic Group" is reviewed. In this group are included (p. 432) the Placer Mountain (Cerrillos) coal beds, which are referred to the Cretaceous "near No. 5" (Fox Hills).

23. 1874. Cope, Edward D.: (On the Cretaceous age of the lignite of the West.)

Philadelphia Acad. Sci., Proc., vol. 26, pp. 10-11, 12-13. 1874. Remarks by Le Conte and Frazer, p. 11.

The author finds evidence of Cretaceous age in the "lignitic beds" of northern Colorado and Le Conte states that coal beds in New Mexico are also Cretaceous.

24. 1874. Cope, Edward D.: Review of the Vertebrata of the Cretaceous period found west of the Mississippi River.

United States geological and geographical survey of the Territories, F. V. Hayden in charge, Bull. (vol. 1, 1st series) No. 2, pp. 5-48. Washington, 1874.

Hayden's reference of the "Placer Mountain" coal beds to the base of his Tertiary lignitic group is quoted and the statement is made that "they are nearer to No. 5 (Fox Hills)."

25. 1874. Cope, E. D. Report on the vertebrate paleontology of Colorado.

United States geological and geographical survey, F. V. Hayden in charge, (7th) annual report (for 1873), pp. 444-533, plates. Washington, 1874.

26. 1874. Cope, Edward D.: Notes on the Eocene and Pliocene lacustrine formations of New Mexico, including descriptions of certain new species of Vertebrata.

Geographic explorations and surveys west of the 100th meridian, by Wheeler, annual report, U. S. Army, Chief of Engineers, Annual Report for 1874, Appendix FF, pp. 115-130, Washington, 1874. (This is not Appendix FF of the Engineer's report, vol. II, 1875.)

Abstract, Am. Jour. Sci., 3d series, vol. 9, p. 151 (⅓ p.). 1875.

(P. 116) The Eocene in the vicinity of the Chama River is described as resting unconformably on coal-bearing rocks which occur below fossiliferous marine rocks of Cretaceous age.

27. 1874. Hayden, F. V.: (General report.)

United States geological survey of the Territories, embracing Colorado, F. V. Hayden in charge, (7th) Annual Report for 1873, pp. 17-82. Washington, 1874.

Abstract, Am. Nat., vol. 9, pp. 173-177. 1875.

(P. 27) The coal beds of western New Mexico are included with others of Cretaceous age.

28. 1874. Hayden, F. V.: Remarks on age of lignitic group.

United States geological and geographical survey of the Ter-

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ritories, F. V. Hayden in charge, Bull. (vol. 1, 1st series) No. 2, pp. 1-2. Washington, 1874.

The authors refer to the coal beds in western Colorado, western New Mexico, and elsewhere as "of undoubted Cretaceous age."

29. 1874. Lesquereux, Leo: On the age of the lignitic formations of the Rocky Mountains.

Am. Jour. Sci., 3d series, vol. 7, pp. 546-557. 1874.

The author discusses the age of the coal beds of New Mexico and repeats his previous reference of them to the Tertiary.

30. 1874. Loew, Oscar: A new fossil resin—"Wheelerite."

Am. Jour. Sci., 3d ser., vol. 7, pp. 571-572. 1874.

Resin was found in "Cretaceous lignite beds" near Nacimiento.

31. 1874. Newberry, John S.: On circles of deposition in secondary sedimentary rock, American and foreign.

New York Lyceum Nat. Hist., Proc., 2d series, pp. 122-124. 1874.

Discussed by Wurtz and Day, ibid., pp. 124, 125. 1874.

Brief reference is made to the Cretaceous rocks of New Mexico.

32. 1874. Newberry, John S.: (On the lignite flora of the far west.)

New York Lyceum Nat. Hist., Proc., 2d series, pp. 78-79. 1874.

The author discusses the geologic age of the coal beds of northwestern New Mexico and states that marine fossils occur in rocks above the coal.

33. 1874. Newberry, John S.: On the lignites and plant beds of western America.

Am. Jour. Sci., 3d series, vol. 7, pp. 399-404. 1874.

The geologic age of the coal beds of New Mexico is discussed.

34. 1874. Raymond, Rossiter W.: Remarks on the occurrence of anthracite in New Mexico.

Am. Inst. Mining Eng., Trans., vol. 2, pp. 140-142. 1874.

The author discusses the age of coal beds near Cerrillos and the chemical character of the coal.

35. 1874. Stevenson, John J.: (Age of Western lignite.)

New York Lyceum Nat. Hist., Proc., vol. 2, pp. 93-94. 1874.

Brief reference is made to the Cretaceous coal beds of western Colorado and northwestern New Mexico.

36. 1875. Cope, Edward D.: Report on the geology of that part of northwestern New Mexico examined during the field season of 1874.

Geographical explorations and surveys west of the 100th meridian, by Wheeler, annual report. Annual Report of the Chief of Engineers, U. S. Army, for 1875, part II. Appendix LL, pp. 981-1017, plates. Washington, 1875.

(Appendix LL is published in separate form, pp. 1-196. 1875.)

(Pp. 996-997) Cretaceous beds, Nos. 3 and 4, are described east of Sandia Mountains (near Hagan). The author's discus-

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sion of the relation of these rocks to the Galisteo sandstone indicates that he regarded the coal beds which are above the marine Cretaceous as No. 4 (Pierre) or younger (although, according to Stevenson, he placed them in No. 3).

(P. 1000) The Cretaceous coal beds extending from Nacimiento Mountains northward are described.

(Pp. 1007-1008) A section is given in which coal is shown in Cretaceous No. 3, at Cristone, overlain by marine rocks, with fossils supposed to indicate Cretaceous No. 4.

37. 1875. COPE, EDWARD D.: The classification and distribution of the Cretaceous deposits of the West.

Vertebrata of the Cretaceous formations of the West, United States geological survey of the Territories, F. V. Hayden in charge, vol. II, pp. 15-41, 4°. Washington, 1875.

(P. 25) Brief reference is made to the Cerrillos coal beds.

38. 1875. COPE, EDWARD D.: The Geology of New Mexico.

Philadelphia Acad. Sci., Proc. (vol. 27), pp. 263-267. 1875. Am. Jour. Sci., 3d series, vol. 10, pp. 152-153. 1875.

(P. 264) Reference is made to the age of the Galisteo sandstone. (P. 267) A section of the rocks west of "Sierra Madre" is given, including both Cretaceous and Tertiary formations.

39. 1875. COPE, EDWARD D.: On the Cretaceous beds of the Galisteo.

Philadelphia Acad. Sci., Proc., for 1875 (vol. 27), pp. 359-360. 1875.

The author discusses Stevenson's paper on "Geological relations of the lignitic group of the Cretaceous," and refers the Galisteo formation to the Triassic on the supposition that former observers had inverted the section.

40. 1875. HOWELL, E. E.: Report on the geology of portions of Utah, Nevada, Arizona, and New Mexico, examined in 1872 and 1873.

Geographical and geological explorations and surveys west of the 100th meridian, Wheeler in charge, Report, vol. 3, geology, pp. 227-301, 4°. Washington, 1875.

(Pp. 275-280) Coal measures in Arizona, Utah, and western New Mexico are correlated with those "east of Mount Taylor" (the southeastern part of the San Juan Basin).

41. 1875. LOEW, OSCAR: Report on the mineralogical, agricultural, and chemical conditions observed in portions of Colorado, New Mexico, and Arizona. (Including analyses of soils and a chapter on "The eruptive rocks of Arizona and New Mexico.")

Geographical and geological explorations and surveys west of the 100th meridian, Wheeler in charge, Report, vol. 3, geology, pp. 569-661, 4°. Washington, 1875.

(Pp. 632-635) An analysis of the anthracite from Placer Mountain (Cerrillos field) is given; also an analysis of bituminous coal from the Rio Puerco near Nacimiento.

(P. 635) The anthracite coal is said to have been mined "40 years ago" (that is, about 1835).

The coal-bearing rocks are referred to the Cretaceous.

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42. 1875. LOEW, OSCAR: Geological and mineralogical report on portions of Colorado and New Mexico.

Geographical explorations and surveys west of the 100th meridian, by Wheeler, annual report. Annual Report of the Chief of Engineers for 1875, part II, Appendix LL, pp. 1017-1036. Washington, 1875.

(Appendix LL is published in separate form, pp. 1-196. 1875.)

(Pp. 1023-1026) Cretaceous coal measures west of Nacimiento Mountains are described; also (p. 1027) those of the Rio Puerco field.

(P. 1028) The anthracite at Placer Mountain was examined; also the coal in Tijeras Canyon and other New Mexico localities.

43. 1876. MEEK, F. B.: Descriptions of the Cretaceous fossils collected on the San Juan exploring expedition under Macomb.

Report of expedition from Santa Fe, New Mexico, to the junction of the Grand and Green rivers of the Great Colorado of the West, in 1859, under Macomb; geological report by Newberry, pp. 119-133, plates, 4°. Washington, 1876.

The fossils described in this report were collected by Newberry in 1859 from the Cretaceous rocks of western New Mexico and Colorado.

(Pp. 121-122) Meek agrees with Newberry in correlating the "Lower Cretaceous" of the latter with the Dakota of the Upper Missouri Cretaceous section, the "Middle Cretaceous" with the Benton and Niobrara formations, and the "Upper Cretaceous" except the highest beds, which were regarded as probably Tertiary, with Pierre and Fox Hills.

44. 1876. NEWBERRY, JOHN S.: Geological report. Report of expedition from Santa Fe, New Mexico, to the junction of the Grand and Green rivers of the Great Colorado of the West, in 1859, under the command of Capt. J. N. Macomb, pp. 9-118, map. plates, 4°. Washington, 1876.

Abstract, *Am.* Jour. Sci., 3d series, vol. 13, pp. 220-221 ($\frac{2}{3}$ p.). 1876.

The Cretaceous is subdivided into three groups; the lowest or "Lower Cretaceous" includes the Dakota of other writers; the "Middle Cretaceous" is made equivalent to Benton and Niobrara, and the "Upper Cretaceous" to the Pierre and Fox Hills (including beds at the top that later proved to be Tertiary).

(P. 38) "Triassic rocks containing . . . silicified trunks of coniferous trees" are reported east of Cerrillos. (The silicified trees east of Cerrillos described by later writers are in the Galisteo sandstone.)

(Pp. 38 and 51) Near the mouth of Galisteo Creek, and also east of the town of Galisteo, fossil leaves said to be of Cretaceous age were found in yellow sandstone below the marine Cretaceous shale. (The description seems to indicate that these may be in rocks older than the Dakota of the present paper.)

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The coal beds at the base of Placer Mountain (the Mesaverde near Madrid) are referred to "Middle Cretaceous," and the bituminous coal is described as changed to anthracite by igneous intrusion.

(Pp. 67-71) In northern New Mexico (north of Jemez Mountains) the three subdivisions of the Cretaceous were recognized and traced westward through southwestern Colorado. The rocks near Sierra del Navajo (near the Colorado-New Mexico line) are described as "Middle" and "Upper Cretaceous." (The Mesaverde, Lewis, and "Laramie" formations of later writers.)

(P. 117) The "Brown sandstones and beds of lignite" near Nacimiento are referred to "Middle Cretaceous." (These are clearly the Mesaverde rocks of later writers.)

45. 1877. Cope, E. D.: Report on the extinct Vertebrata obtained in New Mexico by parties of the expedition of 1874.

United States geographical surveys west of the 100th meridian, Wheeler in charge, Reports, vol. 4, paleontology, 370 pages, plates 22-83, 4°. Washington, 1877.

Abstract, Am. Jour. Sci., 3d series, vol. 15, p. 56 (½ p.). 1878.

(Pp. 1-13) The Cretaceous west of Nacimiento and Gallinas Mountains is described and a cross-section given showing coal in "Cretaceous No. 3" (probably the Mesaverde), succeeded after a covered interval by Puerco.

(Pp. 13-25) The relations of the Eocene to the Cretaceous are discussed at some length.

46. 1877. Hayden, F. V.: United States geological and geographical surveys of the Territories; geological and geographical atlas of Colorado and portions of adjacent territory, by F. V. Hayden, folio 22, double folio atlas sheets, 35 by 22¾ inches. Washington, 1877 (second edition 1881).

Detailed geologic sheets, by Endlich, W. H. Holmes, Peale, Marvine, and C. A. White.

The Cretaceous and younger formations mapped in northwestern New Mexico are Dakota, Colorado (including Benton and Niobrara), Fox Hills (including Fox Hills proper and Pierre), Laramie, and Wasatch.

The marine shale (apparently both Mancos and Lewis), in northern New Mexico west of the Rocky Mountains, is mapped as Colorado shale. The coal-bearing rocks (apparently including both Mesaverde and "Laramie" and probably including also some of the Tertiary) are mapped as Fox Hills. The Wasatch is mapped as resting on the Fox Hills at the eastern margin of the San Juan Basin and on the Laramie farther to the west near Durango and elsewhere.

47. 1877. Macfarlane, James: Coal regions of America, their topography, geology, and development, xvi, 676 pages, 25 maps, New York, 1783, 2d edition; New York, 3d edition, xvi, 700 pages, maps, plates. New York, 1877.

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(Pp. 72-76) The author describes the coal beds of the Cerrillos field, and mentions those of the Rio Puerco and other New Mexico fields.

48. 1877. WHITE, CHARLES A.: Report on the invertebrate fossils collected in portions of New Mexico and Arizona by parties of the expeditions of 1871, 1872, 1873, and 1874. United States geographical surveys west of the 100th meridian, in charge of Wheeler, Reports, vol. 4, paleontology, part 1, 219 pages, plates 1-21, 4°. Washington, 1877.

Abstract, Am. Jour. Sci., 3d series, vol. 12, pp. 62-63 (⅝ p.). 1876.

The Cretaceous is not subdivided in this report. Several of the fossils described are from the Rio Puerco and neighboring regions.

49. 1878. LESQUEREUX, LEO: "The lignitic formation of North America" and "Descriptions of the Tertiary fossil plants."

United States geological and geographical survey of the Territories, F. V. Hayden in charge. Contributions to the fossil flora of the western Territories, parts 1 and 2, the Tertiary flora, by Leo Lesquereux, pp. 3-366, 15 plates, 4°. Washington, 1878.

Reviewed by E. D. Cope, Am. Nat., vol. 12, pp. 243-246. 1878.

(P. 314) The fossil plants from Placière (Cerrillos field) are included in the Tertiary flora. They are *Palmocarpon compositum* Lx.; *Carpites ligatus* Lx.; *Palmocarpon mexicanum* Lx.; *Carpites spiralis* Lx.

The formation (the Mesaverde of the Cerrillos field) is placed in the "first group," together with those in the Raton, Canyon City, Denver, and other coal fields.

50. 1879. COPE, EDWARD D.: The relations of the horizons of extinct Vertebrata of Europe and North America.

United States geological and geographical survey of the Territories, F. V. Hayden in charge, Bull., vol. 5, pp. 33-54. Washington, 1879.

(P. 50) Puerco (?) is shown as occurring above Laramie.

(P. 52) The Puerco marls first observed by Cope in 1874 were referred by Endlich in 1875 "to the lowest place in the Tertiary series, but the absence of fossils renders it difficult to conclude whether they belong here or in the Laramie series."

51. 1879. STEVENSON, JOHN J.: Geology of Galisteo Creek, New Mexico. Am. Jour. Sci., 3d series, vol. 18, pp. 471-475. 1879.

(P. 471) The coal beds north of Placer Mountain (Cerrillos field) are referred to the Laramie, and the underlying shale exposed near the town of Galisteo to the Pierre, Niobrara, and Benton.

The Galisteo sandstone is described as lying unconformably on beds ranging from "Laramie" to Dakota. (This probably is not the Galisteo of other writers.)

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52. 1881. STEVENSON, JOHN J.: Note on the Laramie group of southern New Mexico. Am. Jour. Sci., 3d series, vol. 22, pp. 370-372. 1881.

(P. 370) The statement is made that the "Laramie" beds are practically continuous from Galisteo Creek southward for 150 miles. (This is an error probably arising from the fact that coal occurs near a "San Pedro," about 10 miles south of the Galisteo, and also near another "San Pedro," about 150 miles to the south. The coal near San Pedro and San Antonio referred to by J. M. Robinson, whom Stevenson quotes, is probably the coal of the Tijeras field, but it is not certain how much of the description refers to this field and how much to the Carthage field near the "San Pedro" farther to the south.)

(P. 371) *Ostrea congesta* was observed "high up in the Laramie" of the Cerrillos field, and *Ostrea glabra*, *Anomia*, *Corbula* 3 species, *Camptonectes* ?, and *Tellina* ? were obtained from the coal measures near San Pedro (probably from the Tijeras field) and identified by R. P. Whitfield.

53. 1881. STEVENSON, JOHN J.: Report on geological examinations in southern Colorado and northern New Mexico during the years 1878 and 1879. United States geographical surveys west of 100th meridian, in charge of G. M. Wheeler, Reports, vol. III, Supp., 420 pages, plates, 3 maps, 4°. Washington, 1881.

(Pp. 126-130) The "Galisteo coal field" (Cerrillos field) is briefly described and a detailed section of the coal-bearing rocks near the "western edge of area" is given, and the coal-bearing rocks are referred to the Laramie.

(P. 132) The subdivisions of Lower, Middle, and Upper Cretaceous are adopted, but Upper Cretaceous is here made equivalent to No. 5 (Fox Hills) and a part of No. 4 (Pierre), and Middle Cretaceous is made to include part of No. 4. On the maps Middle Cretaceous is labeled *Colorado*.

(P. 133) The coal beds of the Galisteo area are correlated directly with those of southern Colorado (Trinidad field) and with those of northern Colorado (Denver field) and Wyoming.

(P. 145) The writer states that Newberry regarded the coal beds near Chama and farther to the north and west as younger than those of the "Galisteo coal beds."

(P. 145) The Galisteo coal beds are correlated with Newberry's Upper Cretaceous of the Chama region (Newberry himself had referred them to Middle Cretaceous).

Cope's description of the rocks near Chama in the Wheeler reports (Nos. 26 and 36 of this list) is quoted as proof that Cope was describing the Upper Cretaceous of Newberry. Stevenson uses this for correlating with his Laramie. (P. 155) *Inoceramus* and *Ostrea* were found in the "Laramie" of the Galisteo area.

(Pp. 159-162) The Galisteo sandstone is referred to the Tertiary. (The description and the mapping indicates that the writer's Galisteo is quite different from the Galisteo of other

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authors and probably younger, for it lies with marked unconformity on older rocks. The Galisteo sandstone of other authors is evidently regarded as a part of Stevenson's "Laramie;" see author's figure 49.) (Pp. 328-346) Detailed descriptions and sections of the coal-bearing rocks are given.

54. 1881. Stevenson, John J.: United States geographical surveys west of the 100th meridian, Atlas. 1881.

For geology of New Mexico localities see Atlas sheets Nos. 69(B), 69(D), 70(A), 70(C), 77(B), 78(D).

55. 1882. Cope, Edward D.: The Tertiary formation of the central region of the United States. Am. Nat., vol. 16, pp. 177-195, plate. 1882.

The coal beds near Gallinas Mountains, New Mexico, are mentioned (p. 180) and a section farther north, including the coal measures, near the Colorado-New Mexico line, is described (p. 181).

56. 1882. Stevenson, John J.: Notes on the coal field near Canyon City, Colorado. Am. Phil. Soc., Proc., vol. 19, pp. 505-521. 1882.

Abstract, Am. Jour. Sci., 3d series, vol. 23, p. 152 (½ p.). 1882.

Brief reference is made to the coal measures on Galisteo Creek (Cerrillos field).

57. 1885. Cope, Edward D.: The Vertebrata of the Tertiary formations of the West, book 1, United States geological survey of the Territories, F. V. Hayden in charge, Report, vol. 3, xxxv, 1009 pages, 75 plates, 4°. Washington, 1884.

Reviewed, Science, vol. 5, pp. 467-469. 1885.

(P. 42) In the table of formations Puerco and Laramie are included under post-Cretaceous, although it is stated (p. 4) that the Puerco belongs to the "Tertiary rather than the post-Cretaceous," and Fox Hills is used as a group name to include "Fort Pierre" and "Fox Hills" proper. A cross-section west of Gallinas Mountains is given, showing "lignite" below "Fox Hills."

58. 1885. Cope, Edward D.: Relations of the Puerco and Laramie deposits. Am. Nat., vol. 19, pp. 985-986. 1885.

Observations from David Baldwin's notes are quoted, supplementing previous observations by the writer and others. The Laramie is said to overlie the Fox Hills, to be 2,000 feet thick at Animas City, New Mexico, and to contain characteristic Dinosaurs. The Puerco overlies the Laramie with apparent conformity, but is faunally distinct. It is sometimes included with the Laramie in post-Cretaceous series."

59. 1885. Dutton, C. E.: Mount Taylor and the Zuni plateau. U. S. Geol. Surv., J. W. Powell, Director, 6th Annual Report, 1884-'85, pp. 106-198, plates 11-22. Washington, 1885.

Abstracts, Am. Jour. Sci., 3d series, vol. 34, pp. 155-157, 1887; Science, vol. 10, pp. 317-318, 1887.

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The Cretaceous is not subdivided for purposes of mapping in this paper. Observations were extended eastward to include a part of the valley of the Rio Puerco, but attention is directed principally to the igneous rocks, and little information is given as to the sedimentary formations of this valley.

60. 1885. STEVENSON, JOHN J.: Some notes respecting metamorphism. Am. Phil. Soc., Proc., vol. 22, pp. 161-166. 1885.

Abstract, Am. Jour. Sci., 3d series, vol. 29, p. 414 (½ p.). 1885.

(P. 166) Brief reference is made to the anthracite coal of Placer Mountain (Cerrillos field) and to the metamorphosed coal near Trinidad and near Raton.

61. 1886. WHITE, CHARLES A.: On the relation of the Laramie molluscan fauna to that of the succeeding fresh-water Eocene and other groups. U. S. Geol. Surv., Bull., No. 34, pp. 391-442, 5 plates. Washington, 1886.

Abstracts, Science, vol. 10, pp. 126-127, 1888; Popular Sci. Monthly, vol. 33, p. 420 (½ col.), 1888.

The relation of Laramie and Puerco is discussed and some of the invertebrates from the Puerco near Nacimiento are described.

62. 1889. STEVENSON, JOHN J.: The Mesozoic rocks of southern Colorado and northern New Mexico.

Am. Geol., vol. 3, pp. 391-397. 1889.

(Pp. 391-392) The coal-bearing rocks of the Canyon City, Trinidad, Raton, and Galisteo (Cerrillos) coal fields are referred to the Laramie. Rocks of Fox Hills age are supposed to occur below the coal near Canyon City and Trinidad, Colorado, but to thin out farther to the south and are "supposed to be absent" in the Galisteo area.

63. 1890. COPE, EDWARD D.: (Remarks on the age and stratigraphic components of the Laramie group.)

Geol. Soc. Am., Bull., vol. 1, p. 532, 1890; Am. Nat., vol. 24, p. 569, 1890.

The Puerco containing "about 100 species of mammalia" is said to rest on the Laramie, which also contains some mammals.

64. 1890. NEWBERRY, JOHN S.: The Laramie group. Its geologic relation, its economic importance, and its fauna and flora.

New York Acad. Sci., Trans., vol. 9, pp. 27-32. 1890.

Abstract (by author), Geol. Soc. Am., Bull., vol. 1, pp. 524-527, 527-528, 1890, with discussion by J. B. Tyrrell, L. F. Ward, J. J. Stevenson, and E. D. Cope, pp. 527-532.

Other abstracts, Am. Geol., vol. 5, pp. 118 (¼ p.); Am. Nat., vol. 24, pp. 856-857 (¼ p.).

The coal beds of New Mexico enter into the discussion only incidentally.

65. 1890. STEVENSON, JOHN J.: (Remarks on the differentiation of the Colorado group in Colorado and New Mexico.)

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Geol. Soc. Am., Bull., vol. 1, p. 532 (⅔ p.), 1890; Am. Nat., vol. 24, pp. 568-569, 1890.

Discussion of paper by J. S. Newberry, "The Laramie group." The writer states that the Fox Hills thins out to the south in New Mexico, but that the other Cretaceous formations continue around the mountains to the Rio Grande. (These formations are not known to exist over a large area at the southern end of the mountains.)

66. 1890. WARD, LESTER F.: (Remarks on the age of the Laramie group.) Geol. Soc. Am., Bull., vol. 1, pp. 529-532, 1890; Am. Nat., vol. 24, pp. 564-568, 1890.

Discussion of paper by J. S. Newberry on "The Laramie group." Discussion in which the coal beds of New Mexico are assumed to be Laramie.

67. 1893. EMMONS, SAMUEL FRANKLIN: Excursion to the Canyon of the Colorado. Itinerary, Denver, Colorado, to Albuquerque, New Mexico.

Int. Cong. Geol., Compte Rendu, 5th session, pp. 464-468. 1893. The reference of the coal beds near Ortiz in the Cerrillos field to Laramie is accepted.

68. 1895. OSBORN, H. F., and EARLE, CHARLES: Fossil mammals of the Puerco beds. Am. Mus. Nat. Hist., Bull., vol. vii, pp. 1-70, figs. 1-21. 1895.

The coal beds below the Puerco are assumed to be Laramie, and the Puerco is said to contain "several Laramie reptiles" (p. 4).

69. 1896. STEVENSON, JOHN J.: The Cerrillos coal fields near Santa Fe, New Mexico. N. Y. Acad. Sci., Trans., vol. xv, pp. 105-122. 1896.

Abstract, Geol. Soc. Am., Bull., vol. vii, pp. 525-527; Science, new ser., vol. iii, pp. 392-394. 1896.

(P. 111) The statement is reiterated that the Fox Hills stage of the Rocky Mountain region is not represented in this area and the coal beds are assumed to be Laramie. Sections of the coal-bearing rocks are given, the characteristics of the coal described, and several analyses of the coal are given. The metamorphosis of the bituminous coal into anthracite is discussed.

70. 1897. FLEMING, JOHN W.: (Coal mines of New Mexico.) Report of the Governor of New Mexico to the Secretary of the Interior. Washington, 1897, pp. 91-115.

The report contains a geologic section of the rocks exposed near Madrid in the Cerrillos coal field. Coal mines in northern New Mexico near Monero are referred to.

71. 1898. FLEMING, JOHN W.: (Coal mines of New Mexico.) Report of the Governor of New Mexico to the Secretary of the Interior. Washington, 1898, pp. 56-86.

The report contains a geologic section of rocks exposed near Madrid in the Cerrillos coal field.

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The mines at Monero are described, where three beds of coal ranging in thickness from 3 feet 6 inches to 3 feet 10 inches have been opened.

72. 1898. HERRICK, C. L.: The geology of the San Pedro and the Albuquerque districts (New Mexico).

Denison Univ., Sci. Lab., Bull., vol. xi, pp. 93-116, pl. xiii. 1898.

The coal-bearing rocks outcropping on the Rio Puerco (p. 97) and those of the Tijeras field (pp. 108-109) are described as Cretaceous.

(P. 112) The coal beds of the Cerrillos field at Waldo, Madrid, and Omera are briefly mentioned. A sketch map of the geologic formations accompanies the paper.

73. 1898. SPENCER, ARTHUR COE: The Upper Cretaceous section in southwestern Colorado. Abstract, Science, new ser., vol. vii, p. 143 (¼ p.). 1898.

The statement is made that above the Dakota "comes a series of shales, known to embrace the Benton, Niobrara, and a part of the Pierre, which can not be divided on lithologic grounds. The upper part of the section . . . consists of massive sandstones in which both the Fox Hills equivalent and that of the Laramie may prove to be present." No mention is made of the Lewis shale.

74. 1899. FLEMING, JOHN W.: (Coal mines of New Mexico.) Report of the Governor of New Mexico to the Secretary of the Interior. Washington, 1899, pp. 164-209.

The coal mines near Madrid in the Cerrillos field are described and the geologic relations of the coal beds shown by columnar section.

The mines at Monero are also described.

75. 1899. CROSS, WHITMAN: U. S. Geol. Survey, Geol. Atlas of U. S., folio No. 60. 1899.

(Pp. 4 and 5) The coal-bearing rocks are described as the *Mesaverde* formation and are underlain by *Mancos* shale and overlain by *Lewis* shale.

(P. 4) The Lewis is described as about 2,000 feet thick. The occurrence of coal-bearing rocks above the Lewis is noted, but doubt is cast on their assignment to the Laramie.

(P. 5) The lower part of the Mancos shale contains the following characteristic Benton fossils: *Gryphæa newberryi; Ostrea lugubris; Ostrea congesta; Inoceramus labiatus; Inoceramus fragilis; Inoceramus dimidius; Prionocyclus macombi; Baculites gracilis; Scaphites warreni; Anatina* sp.?; *Plicatula* n. sp.

The upper part of the Mancos contains the following Pierre fossils (this revised list has been prepared for the present paper by T. W. Stanton): *Inoceramus barabini; Inoceramus* sp.; *Inoceramus sagensis; Syncyclonema rigida; Scaphites* sp.;

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Baculites sp., a large form resembling *Baculites ovatus* or *Baculites compressus; Arca* sp.?; *Turritella* sp.?

76. 1900. Fleming, John W.: Report of the mine inspector for the Tertiary of New Mexico.

Report of the Governor of New Mexico to the Secretary of the Interior. Washington, 1900, pp. 279-314.

The mines of the Cerrillos coal field are described and those of Monero are mentioned.

77. 1900. Herrick, C. L., and Johnson, D. W.: The geology of the Albuquerque sheet (New Mexico).

Denison Univ. Sci. Lab., Bull., vol. xi, art. ix, pp. 175-239, pls. xxvii-lviii. 1900.

Hadley Lab. Univ. of New Mexico, Bull., vol. ii, pt. i, 1900, pp. 1-67, 32 pls., colored geologic map in pocket. 1900.

(Pp. 187-188) A *Gastropod zone* is described as occurring about 40 feet above the Dakota sandstone, followed upward by the *Tres Hermanos sandstone* and a *Concretion zone*, which "abounds in large ammonites shells and large species of *Pinna* and *Baculites*." This zone was recognized, according to these writers, near Cabezon, about 20 miles to the northwest and near Una del Gato (Hagan field), about 30 miles to the east. These three zones are close together, and from them, in the Rio Puerco, Hagan, and Tijeras fields, the following fossils were collected: [It is not always possible to determine from the descriptions when the authors refer to the Concretion zone and when to the Cephalopod zone. Hence it is possible that some of the following species may have come from the Cephalopod zone.] *Ostrea translucida* M. & H.; *Exogyra læviscula* Roemer; *Exogyra columbella* Meek; *Mactra* (?) *subquadrata* H. & J.; *Tapes cyrimeriformis* Stanton; *Caryates veta* Whitfield; *Pholadomya subventricosa* M. & H.; *Liopistha concentrica* Stanton; *Camptonectes symmetricus* H. & J.; *Dosinia* sp.; *Chemnitzia* sp.; *Sigaretus textilis* Stanton; *Baculites gracilis Shumard* ?; *Prionotropis woolgari* Mantell; a thick shale (the principal part of the Mancos) occurs above the *Concretion zone*, but its thickness is not given. Apparently the space occupied by it is represented by the hiatus in the section east of Prieta Mesa, given in plate 22. (Johnson has stated personally to the present writer that the shale between the "*Concretion zone*" and the "*Cephalopod zone*" was roughly estimated at 1,000 feet.) A *Cephalopod zone* occurs about 100 feet from the top of this shale (the present writer found this zone to be about 300 feet from the top), and above it occurs the *Punta de la Mesa sandstone*—the basal member of the yellow sandstones described as the "*Prieta Series*." These sandstones, together with the Cephalopod zone, are referred to the Fox Hills. [The sandstones are now referred to the Mesaverde and the Cephalopod zone to the Benton.] From them the following fossils were identified: *Ostrea lugubris* Conrad; *Ostrea sannionensis* White; *Gryphæa*

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vesicularis Lam.; *Inoceramus fragilis* H. & M.; *Pinna petrina* White; *Rostellites ambigua* Stanton; *Buchiceras swallovi* Shumard; *Sphenodiscus lenticulare* Owen; *Placenticeras placenta* De Kay; *Placenticeras costata* H. & J.; *Pholadomya subventricosa; Scaphites nodosus* M. & H.; *Scaphites* sp. [The description of locality is vague. The Scaphites probably are from near the middle of the Mancos shale.]

The upper part of the "Prieta series" contains marine shells said to be of Fox Hills age and fossil plants "not identifiable with familiar Laramie species." The following fossils were collected from these coal-bearing rocks in the Rio Puerco, Hagan, and Tijeras fields: *Ostrea prudentia* White; *Ostrea franklini* Coquand ?; *Exogyra texana* Roemer; *Exogyra winchelli* White; *Mactra pulchella* H. & J.; *Tellina* (?) *perlata* H. & J.; *Tellina equilateralis* Meek; *Idonarca* (?) *depressa* White; *Cardium pauperculum* Meek; *Cardium* sp.; *Legumen* (?) *oppressum* Conrad; *Chemnitzia coalvillensis* Meek; *Gyrodes depressa* Meek; *Pyropsis bairdi* M. & H.; *Rostellites dalli* Stanton; *Valutomorpha* (?) *nova-mexicana* H. & J.; *Harpa* (?) *occidentalis* H. & J.; *Baculites asper* Morton; shark's teeth; plants.

(P. 17) Tertiary beds "with remains of vertebrates which we presume to be representatives of lower Tertiary strata" lie stratigraphically above the coal-bearing rocks on the Rio Puerco.

78. 1900. Herrick, C. L.: Report of a geological reconnaissance in western Socorro and Valencia counties, New Mexico.

Am. Geol., vol. xxv, pp. 331-346, pls. viii-lx. 1900.

This paper supplements to some extent the information given in the description of the Albuquerque sheet (p. 338). A section measured east of Prieta Mesa is given, in which the *Cephalopod zone* is placed only about 100 feet above the *Tres Hermanos sandstone* (this Cephalopod zone seems to be the Concretion zone of Herrick and Johnson). The coal-bearing sandstones and shales (Mesaverde) are about 1,600 feet thick and are overlain by Tertiary.

79. 1901. Herrick, C. L.: Applications of geology to economic problems in New Mexico. Int. Mg. Cong., 4th session, Proc., pp. 61-64. 1901.

(P. 64) Attention is called to the fact that some of the New Mexico coal-bearing rocks formerly supposed to be Laramie contain *Ostrea glabra* and are overlain by marine Cretaceous beds "with fossils like those of the upper Fox Hills group."

80. 1901. Sheridan, Jo E.: Report of the mine inspector for the Territory of New Mexico.

Report of the Governor of New Mexico to the Secretary of the Interior. Washington, 1901, pp. 309-351.

The coal mines of the Cerrillos field and those at Monero are described.

81. 1902. Lee, W. T.: The Morrison shales of southern Colorado and northern New Mexico.

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Jour. Geol., vol. 10, pp. 36-58, 7 figs. 1902.

The Exeter sandstone is named and described in this paper.

82. 1902. STORRS, L. S.: The Rocky Mountain coal fields. U. S. Geol. Surv., 22d Ann. Rept., pt. 3, pp. 415-471, 2 pls., 1 fig. 1902.

The coal beds of the San Juan Basin and of the Cerrillos and Hagan fields are referred to the Laramie and the coal of the latter two is said to lie "under the Tertiary beds."

83. 1903. JOHNSON, D. W.: Geology of the Cerrillos Hills, New Mexico. Part I, General geology; part II, paleontology; part III, petrography.

School of Mines Quart., vol. 24, pp. 303-350, 7 pls., 7 figs.; pp. 456-500, 10 pls,, 6 figs,, 1903; pp. 173-246, 14 pls., 1903; vol. 25, pp. 69-98, 5 pls., 1903.

The reports result from the work done in 1899-1902. Among others the following propositions are supported:

(1) The Santa Fe marls of Hayden . . . represent the time from the early Loup Fork Tertiary to the Recent period.

(2) The Galisteo Group of Hayden consists of red beds of late Cretaceous, probably Laramie age.

(3) The coal series, or Madrid Group, is of Fox Hills age.

(4) Pierre, Benton, and probably Dakota and Jura-Triassic beds, are also present in the district.

(Vol. 24, pp. 336-338) The Galisteo sandstone is referred doubtfully to the Laramie and is described as consisting of red sedimentary rocks similar lithologically to the older "Red Beds," and lying conformably (? see discussion on this point in the present paper) on the Madrid group. They contain fossil wood which, according to F. H. Knowlton, indicates a species of *Quercus* and is evidently of Upper Cretaceous or later age.

(Pp. 338-344) The Madrid Coal Group is described as 1,500 to 2,000 feet thick. The coal is said to be in the lower part of this group. The author's figure 5 makes the base of the group rest on the lowest sheet of intrusive igneous rock at Madrid and places the rocks below this sheet in the Pierre. (This would place in the Pierre below the Madrid group a considerable thickness of sandstone and several thin beds of coal which obviously belong in the Madrid or coal-bearing formation.) The base of the Madrid group is obviously drawn but little below the coals that have been mined, for the writer states (p. 340) that "the coal in the *lower portion* of the Madrid group has proven of great interest to geologists, and so many references have been made to it." etcetera.

(Pp. 344-347) The Pierre group is described as consisting of shale and sandstone. A section (p. 346) places 162 feet of sandstone above the dark-colored shale (Mancos) in the Pierre.

(P. 347) No undoubted Niobrara was found, but the Benton and Dakota occur.

(Pp. 477-493) The economic features of the coal are described. Fossil leaves, identified by Knowlton (p. 178, Paleontology) as

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Ficus rhamroides Knowlton, *Ficus uncata* Lesquereux, *Quercus* ? sp., and *Aralia* ? sp. were found above the highest coal bed east of Madrid.

In some places fossils characteristic of the Colorado and Montana groups seem to occur together (p. 182) as follows: *Inoceramus labiatus* Schloth. (Colorado form); *Stantonoceras pseudocastatum* Johnson (Colorado form); *Astarte evansi* H. and M. (Montana form); *Placenticeras placenta* De Kay (Montana form); *Baculites anceps* Lamarck.

At another locality (p. 183) *Ostrea lugubris* Conrad (Colorado form) and *Astarte evansi* H. and M. (Montana form) were found together.

The following faunas of the Cerrillos region are described:

Pierre fauna—*Lingula subspatulata* H. and M.; *Ostrea anomioides* var. *nanus* Johnson; ? *Ostrea congesta* Conrad; *Inoceramus simpsoni* Meek; *Inoceramus vanuxemi* M. and H.; *Inoceramus balchii* M. and H.; *Inoceramus cripsi* var. *barabini* Morton; *Inoceramus irregularis* Johnson; *Inoceramus* sp.; *Endocostea typica* Whitfield; *Endocostea brooksi* Johnson; *Arca madridensis* Johnson; *Trigonarea obliqua* Meek; *Nucula subplana* M. and H.; *Astarte evansi* (H. and M.) Whitfield; *Protocardia rara* E. and S.; *Cyprimeria* ? *sulcata* Johnson; *Solen cuneatus* Gabb; *Corbula mematophora* var. *fitchi* Johnson; *Natica* sp.; *Turritella galisteoensis* Johnson; *Rostellario* ? *texana* Conrad; *Tritonium kanabense* Stanton; *Admetopsis* ? *elevata* Johnson; *Helicoceras pariense* White; *Baculites anceps* Lamarck; *Baculites* sp.; *Placenticeras placenta* De Kay; *Placenticeras* ? sp.; *Placenticeras* ? *intermedium* Johnson; *Placenticeras* ? *rotundatum* Johnson; *Stantonoceras guadaloupæ* Roemer; *Beryx* sp.

Benton fauna—*Ostrea lugubris* Conrad; *Inoceramus fragilis* H. and M.; *Inoceramus labiatus* Schloth.; *Inoceramus dimidius* White; *Inoceramus strongi* Johnson; *Acmæa cerrillosensis* Johnson; *Scurria coniformis* Johnson; *Rostellites dalli* var. *wellsi* Johnson; *Rostellites ambigua* Stanton; *Prionocyclus wyomingensis* Meek; *Prionocyclus macombi* Meek; *Prionocyclus* sp.; *Prionotropis woolgari* Mantell; *Scaphites warreni* M. and H.; *Beryx* sp.; *Baculites anceps* Lamarck; *Stantonoceras pseudocostatum* Johnson.

84. 1903. Reagan, Albert B.: Geology of the Jemez-Albuquerque region, New Mexico. Am. Geol., vol. 31, pp. 67-111, 7 pls. 1903.

See also Ind. Acad. Sci., Proc., pp. 187-198. 1903.

A geologic sketch map, showing the distribution of the formations from Cabezon eastward to Hagan, is given.

(P. 79) The author's *Fox Hills* includes the sandy rocks below the coal; and the coal-bearing rocks, 500 feet thick, are described as "*Fort Union*" or "*Laramie*." His "Fox Hills" and "Fort Union" constitute the "Fox Hills" of Herrick and Johnson and the *Mesaverde* of later writers.

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(P. 81) The colored sediments lying unconformably on the coal-bearing rocks south of San Isidro (in the Rio Puerco field) are referred to the Puerco.

85. 1904. JONES, FAYETTE ALEXANDER: New Mexico mines and minerals. World's Fair edition, 1904. Santa Fe, New Mexico, the New Mexican Printing Company, 1904. 349 pp., 50 figs.

(P. 7) The New Mexico coal beds are referred to Fox Hills and Laramie. The coal of the Cerrillos field is referred to the Fox Hills.

86. 1904. KEYES, CHARLES ROLLIN: Unconformity of the Cretaceous on older rocks in central New Mexico. Am. Jour. Sci., 4th ser., vol. 18, pp. 360-362, 2 figs. 1904.

Cretaceous sandstone (2,000 feet thick) lying above rocks of Montana age (presumably the coal-bearing sandstones described in this paper as Mesaverde) are referred to the Laramie.

87. 1904. KEYES, CHARLES ROLLIN: The Hagan coal field (New Mexico). Eng. & Mg. Jour., vol. 78, pp. 670-671, 3 figs. 1904.

The Hagan coal field is described with sketch maps and geologic sections. A detailed section is given of the coal-bearing rocks measured at the Hagan mine.

88. 1904. SHERIDAN, JO E.: Annual report of the mine inspector for the Territory of New Mexico.

U. S. Mine Inspector for the Territory of New Mexico, Ann. Rept. to the Secretary of the Interior for the year ended June 30, 1904. Washington, 1904, 79 pp.

(Pp. 32-38) The coal beds of the Cerrillos, Una del Gato (Hagan), and Monero fields are described.

89. 1904. LAKES, ARTHUR: The coal fields of Colorado.

Colo. Sch. Mines, Bull., vol. 2, no. 2, pp. 11-23, 2 figs. 1904.

90. 1905. OGILVIE, IDA H.: The high altitude conoplain; a topographic form illustrated in the Ortiz Mountains (New Mexico).

Am. Geol., vol. 36, pp. 27-34, 1 pl. 1905.

The conoplain described lies across the eroded coal beds of the Cerrillos and Hagan fields.

91. 1905. SHERIDAN, JO E.: Annual report of the mine inspector for the Territory of New Mexico.

U. S. Mine Inspector for the Territory of New Mexico, Ann. Rept. to the Secretary of the Interior for the year ended June 30, 1905. Washington, 1905.

(Pp. 40–48) Describes the Cerrillos and Una del Gato (Hagan) coal fields.

92. 1905. STANTON, T. W.: Morrison formation and its relation with the Comanche series and the Dakota formation.

Jour. Geol. vol. XIII, pp. 657–669. 1905.

(P. 664) Some of the rocks in northeastern New Mexico and southeastern Colorado heretofore called Dakota are shown on fossil evidence to be Comanche.

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(P. 666) Near Canyon City, Colo., the shale which separates the two plates of so-called Dakota sandstone was found to contain a Comanche fauna.

93. 1906. Griffith, William: Kinds and occurrence of anthracite coal. Min. Mag., vol. 13, no. 3, pp. 214-221, March. 1906.

(P. 218) Brief reference is made to the Cerrillos coal.

94. 1906. Jones, Fayette A.: Mineral resources of New Mexico. Am. Min. Cong., 8th Ann. Sess., pp. 135-143. 1906.

(P. 143) Brief reference is made to the coal beds of New Mexico.

95. 1906. Keyes, Charles R.: Orotaxial significance of certain unconformities. Am. Jour. Sci., 4th ser., vol. 21, pp. 296-300, 2 figs., April, 1906.

A generalized section is given showing the position of certain unconformities in the sedimentary rocks of New Mexico (two of which—between "Dakotan and Coloradan," and between "Montanan and Laramian"—affect rocks described in the present paper, but which are not confirmed by the present writer).

96. 1906. Keyes, Charles Rollin: Geological section of New Mexico. Science, new ser., vol. 23, pp. 921-922, June 15, 1906.

A generalized geologic section is given.

97. 1906. Lee, Willis T.: The Engle coal field, New Mexico. U. S. Geol. Survey, Bull. no. 285, p. 240. 1906.

The coal beds of the Engle field contain numerous plant remains and rest on rocks containing a Benton fauna. Lying unconformably on the coal-bearing rocks are red sedimentary rocks similar in general appearance to the Galisteo sandstone of the Cerrillos field. *Triceratops* bones were found in these red rocks. The correlation of the coal with that at Cerrillos and Raton is suggested.

98. 1906. Merrill, George P.: Contributions to the history of American geology. U. S. Nat. Mus., Ann. Rept. 1904, pp. 189-733, 37 pls., 141 figs. 1906.

Several brief sketches are given of the men who worked in New Mexico and of the results obtained by them. Chapter X is devoted to the Laramie question.

99. 1906. Ritter, Etienne A.: Les basin lignitiferes et houillers des Montagnes Rocheuses. Annales des Mines, 10° ser., t. 10, livr. 7, pp. 5-84. 1906.

(P. 52) The Fox Hills age for the Cerrillos coal measures is accepted.

100. 1906. Schrader, Frank Charles: The Durango-Gallup coal field of Colorado and New Mexico. U. S. Geol. Survey, Bull. no. 285, pp. 241-258. 1906.

A map is presented outlining the north, east, and south sides of the principal part of the coal fields of the San Juan basin. Five groups of coal beds are mapped: (1) a *Colorado* group in the southwestern part of the field; (2) a *lower Montana* group—

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relation to the Mesaverde unknown—occurring also in the southwestern part of the field; (3) a *Mesaverde* group occurring on the north and east parts of the field; (4) an "*upper Montana* group—relation to the Mesaverde unknown"—occurring in the south and southeastern parts of the field; and (5) a "*Laramie*" group occurring in the northern and northeastern parts.

The "Laramie" is shown from Colorado as far south as Gallinas Mountains, New Mexico, and is the same as the "Laramie" of other writers; the Mesaverde extends as far south as the Puerco River. The upper Montana group occurs in the southeastern part of the field near Cabezon, and is the Mesaverde of later writers. The other groups occur only west of the area described by the writer.

(P. 251) The Chico Arroyo district, extending from Sierra Nacimiento to Mount Taylor, contains coal-bearing rocks 2,000 to 3,000 feet thick, which are said to lie unconformably on the Mesaverde and to contain fossils which indicate that they are younger than Mesaverde. These constitute the "upper Montana coal group." (The "Mesaverde" and the "upper Montana coal group" of Schrader together constitute the Mesaverde of Gardner and the present writer.)

101. 1906. Sheridan, Jo E.: Report of the mine inspector for the Territory of New Mexico to the Secretary of the Interior for the year ended June 30, 1906. Washington, Government Printing Office, 1906. 87 pp.

(Pp. 51-57) The Cerrillos and Una del Gato (Hagan) coal fields are described.

102. 1906. Sheridan, Jo E.: Present conditions and future prospects of the coal-mining industry in New Mexico.

Annual Report U. S. Mine Inspector for the Territory of New Mexico to the Governor of New Mexico, Santa Fe, 1906, 134 pp.

(Pp. 66-69) The coal mines at Monero are described. Three beds of coal varying from 3 to 4 feet in thickness are said to be worked.

(Pp. 70-78) The mines in the Cerrillos and Una del Gato (Hagan) fields are briefly described.

103. 1907. Campbell, Marius R.: The Una del Gato coal field, Sandoval County, New Mexico, U. S. Geol. Survey, Bull. no. 316, pp. 427-430, 1 fig. 1907.

The Una del Gato (Hagan) field is described principally from an economic point of view. A section of the rocks measured by Charles R. Keyes near Sloan mine is given. The coals are correlated with those of the Cerrillos field, and the statement is made that "it is highly probable that they are Laramie."

104. 1907. Lee, Willis T.: Note on the red beds of the Rio Grande region in central New Mexico.

Jour. Geology, vol. 15, no. 1, pp. 52-58. 1907.

(P. 57) Coal-bearing rocks near Elephant Butte, New Mexico,

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are described as underlying red beds containing bones of *Triceratops*, which suggest late Cretaceous age. Red beds of similar appearance near Cerrillos, New Mexico, known as Galisteo sandstone have also been regarded as late Cretaceous, and the correlation of the two is suggested.

105. 1907. SHALER, MILLARD K.: A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico. U. S. Geol. Survey, Bull. no. 316, pp. 376-426, 2 pls. 1907.

The paper deals with the geology of the western part of the San Juan Basin.

106. 1907. SHERIDAN, JO E.: Report of the mine inspector for the Territory of New Mexico to the Secretary of the Interior for the fiscal year ended June 30, 1907.

Washington, Government Printing Office, 1907, 48 pp.

(Pp. 33-36) The coal beds of the Cerrillos and Hagan fields are described.

107. 1908. CAMPBELL, M. R.: Coal fields of the United States. Map, with explanations. U. S. Geol. Surv. 1908.

108. 1908. JONES, FAYETTE A.: Epitome of the economic geology of New Mexico. Published by direction of the New Mexico Bureau of Immigration. 1908. 47 pp.

Brief references are made to the coal beds.

109. 1908. SHIMER, H. W., and BLODGETT, MILDRED E.: The stratigraphy of the Mount Taylor region, New Mexico. Am. Jour. Sci., 4th ser., vol. 25, pp. 53-67, 4 figs., January, 1908.

This paper is a report on observations made in 1906 in the Rio Puerco Valley south of Cabezon.

(P. 54) The "Gastropod Zone" near the base of the Cretaceous; the "Concretion (Septaria) Zone" (near the Tres Hermanos sandstone) and the "Cephalopod Zone" (near the top of the Mancos) of Herrick and Johnson were recognized, but most of the fossils collected are from the latter two zones, although one fossil, *Gryphæa newberryi* Stanton, was found below the "Septaria Zone."

(P. 56) The following fossils of Benton age were collected from the "Septaria Zone," about 8 miles southwest of Casa Salazar: *Placenticeras* ? *rotundatum* Johnson; ? *Prionocyclus wyomingensis* Meek; *Lima utahensis* Stanton; *Stantonoceras stantoni* Johnson; *Scaphites* sp.; *Turritella whitei* var. *stantoni* S. and B.; ? *Ostrea lugubris* Conrad.

(P. 57) The "Septaria Zone" of these authors is said to disappear under the surface a short distance north of Casa Salazar. (This fixes its horizon near the base of the thick shale above the Tres Hermanos sandstone.)

(P. 57) About seven miles southwest of Cabezon (supposed to be near the top of the Mancos shale), the following fossils were collected: *Trigonarca depressa* White; **Lucina* cf. *subundata* H. and M.; **Pteria linguiformis* (E. and S.); ***Solemya* ?

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obscura Stanton; *Pinna* sp.; ***Actæon propinquus* Stanton. (Those marked * are said to be of Pierre age, and those marked ** to be of Benton age.)

(P. 58) About 16 miles southeast of Cabezon (probably near the top of the Mancos shale) the following fossils were found: *Prionotropis woolgari* (Mantell); *Placenticeras placenta* (Dekay); *Astarte evansi* (H. & M.) Whitfield, and 7 miles farther southeast, at about the same horizon as those named above, the following were collected: *Gryphæa newberryi* Stanton; *Inoceramus labiatus* (Schlotheim); *Inoceramus dimidius* var. *labiatoides* S. and B.; ?*Yoldia subelliptica* Stanton; *Anomia propatoris* White; *Ostrea lugubris* Conrad; *Ostrea anomioides* var. *nanus* Johnson; *Cardium pauperculum* Meek; *Turritella whitei* var. *stantoni* S. and B.; *Lunatia concinna* (H. and M.); *Prionotropis hyatti* Stanton; *Prionotropis woolgari* (Mantell).

(Pp. 59-60) Evidence is given to the effect that there are two "Septaria zones" below the "Caphalopod zone" of Herrick and Johnson, which contain a fauna said to be "almost totally distinct from the Septaria fauna. The authors conclude that the strata yielding the fossils described vary in age from Benton to doubtful Pierre and "show a commingling of many species of the Colorado formations with a few of the Montana. This would apparently indicate an upper Fort Benton age for the beds unless we suppose that the apparent absence of clear water in this region during Niobrara times would cause the absence of the typical Niobrara fauna and the persistence of the Fort Benton fauna to Montana times. Under such a supposition, some of these intermediate strata would represent the Niobrara time, without the presence of the typical Niobrara fauna."

110. 1909. Gardner, James H.: The coal field between Gallina and Raton Spring, New Mexico, in the San Juan coal region.

U. S. Geol. Survey, Bull. 341, pp. 335-351, 1 pl. (map). 1909.

Two coal-bearing formations southwest of Nacimiento Mountains are described. They are the Mesaverde, which includes Schrader's "Upper Montana Group," and the "Laramie." These are separated by Lewis shale, which is said to be 2,000 feet thick near Gallina and only 250 feet thick on the Arroyo Torreons, about 30 miles to the southwest. Several geologic sections are given showing the relations of the coal beds to other rocks.

(P. 338) "At a point 10 miles north of Gallina a part of the (Mancos) becomes arenaceous and forms a hogback in the shale valley. This sandy bed is about 30 feet thick and about 275 feet below the top of the formation. It is no doubt the beginning of the sandstone and shale formation that increases in thickness toward the south and is coal-bearing on the south side of the (San Juan) basin."

111. 1909. Lee, Willis T.: Unconformity in the so-called Laramie of the Raton coal field, New Mexico.

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Geol. Soc. Am. Bull., vol. 20, pp. 357-368, 3 plates, 1 fig. 1909.

The paper presents evidence that the coal-bearing rocks of the Raton field are divisible into two formations, the lower one possibly older than Laramie and the upper one of post-Laramie age.

112. 1909. LEE, WILLIS T.: The Manzano group of the Rio Grande Valley, New Mexico. U. S. Geol. Survey, Bull. 389, pp. 5-40, 5 pls., 9 figs. 1909.

The paper includes geologic sections of the older rocks up to and including the Dakota sandstone in the Cerrillos and Hagan fields.

113. 1909. STANTON, T. W.: The age and stratigraphic relations of the "Ceratops beds" of Wyoming and Montana.

Washington Acad. Sci., Proc., Vol. XI, pp. 239-293. 1909.

(P. 274) The paper gives the names of invertebrates from the "Laramie" of southwest Colorado.

114. 1910. DARTON, NELSON HORATIO: A reconnaissance of parts of northwestern New Mexico and northern Arizona.

U. S. Geol. Survey, Bull. 435, 88 pp., 17 pls., 8 figs. 1910.

The geology along the Santa Fe Railway from Albuquerque westward is described. The Cretaceous consists of the following formations, given in descending order: *Laramie*, coal-bearing; *Lewis* shale; *Mesaverde*, coal-bearing; *Mancos* shale, locally coal-bearing; *Dakota* sandstone.

(P. 58) Gardner's results are accepted for the Nacimiento region and Herrick and Johnson's for the Rio Puerco region. Herrick's section in the Rio Puerco Valley (78, p. 338) is quoted with several changes, and the reference of the coal-bearing rocks including the "Punta de la Mesa sandstone" to the Fox Hills is accepted.

A section of rocks exposed at Laguna, west of the Rio Puerco coal field, was measured. The following fossils occur about 550 feet above the base of this section: *Exogyra columbella* Meek; *Gryphæa* sp., probably a variety of *Gryphæa newberryi; Avicula gastrodes* Meek ?; *Cardium, Panopea, Turritella, Rostellites,* and *Fusus* sp.

About 100 feet lower in the section the following species were collected: *Exogyra columbella* Meek; *Pecten* sp.; *Pinna petrina* White; *Inoceramus* ?, *Leda, Cardium,* and *Lucina* ? sp.; *Isocardia* n. sp.; *Cyprimeria* ? sp., *Corbula* sp.; *Liopistha* (Psilomya) *concentrica* Stanton; *Turritella whitei* Stanton; *Tritonium kanobense* Stanton; *Actæon, Cinulia, Turrilites* ?, or *Heteroceras* sp. Doctor Stanton is quoted as reporting that these fossils indicate a horizon in the Benton formation.

115. 1910. GARDNER, JAMES H.: Isolated coal fields in Santa Fe and San Miguel counties, New Mexico.

U. S. Geol. Survey, Bull. 381, pp. 447-451. 1910.

No. Date.

A part of this paper is devoted to the "Omara Coal Field," and the coal beds at the Omara mine are correlated with those near Madrid. (These localities are at opposite extremities of the Cerrillos field.)

116. 1910. GARDNER, JAMES H.: The coal field between San Mateo and Cuba, New Mexico. U. S. Geol. Survey, Bull. 381, pp. 461-473, 1 pl. (map). 1910.

The coal-bearing formations of the southeastern part of the San Juan Basin are described as Mesaverde and "Laramie." A detailed section of the Mesaverde on Arroyo Torreons (p. 470) shows a thickness of 1,328 feet.

The statement is made (p. 462) that the Mesaverde "is now known to encircle the San Juan Basin. The same is true of the overlying conformable Lewis shale and 'Laramie' formation."

117. 1910. GARDNER, JAMES H.: The Puerco and Torrejon formations of the Nacimiento group. Jour. Geology, vol. 18, no. 8, pp. 702-741, 3 pls., 8 figs. 1910.

The Tertiary and late Cretaceous formations of the San Juan Basin west of Nacimiento Mountains are described.

The Tertiary beds rest unconformably on the "Laramie," and the Mesaverde coal measures are separated from the "Laramie" by the Lewis shale.

118. 1910. LINDGREN, WALDEMAR; GRATON, LOUIS C., and GORDON, CHARLES H.: The ore deposits of New Mexico.

U. S. Geol. Survey, Prof. Paper 68, 361 pp., 22 pls., 33 figs. 1910.

Brief references are made in many places to the coal-bearing formations of New Mexico.

119. 1911. LEE, WILLIS T.: Further evidence of an unconformity in the so-called Laramie of the Raton coal field, New Mexico. (Abstract.) Bull. Geol. Soc. Am., Vol. 22, p. 717. 1911.

The unconformity separating the coal-bearing rocks of the Raton coal field into a possible pre-Laramie and a post-Laramie formation was traced around the Raton and Trinidad coal field.

120. ——. LEE, WILLIS T.: Correlation of rocks in the isolated coal fields around the southern end of the Rocky Mountains in New Mexico.

(The preliminary announcement of the results contained in this paper was made at the Washington meeting of the Geological Society of America, 1911.)

121. 1912. STOSE, G. W.: The Apishapa folio, Colorado. (In press.) U. S. Geol. Surv., Geol. Atlas U. S. No. 191.

The shale separating the two plates of so-called Dakota sandstone and the lower plate of this sandstone are referred on fossil evidence to Comanche. The upper plate of sandstone is referred to Dakota.

122. 1912. RICHARDSON, G. B.: The Monument Creek group. Bull. Geol. Soc. Am., vol. —, pp. —. 1912. (In press.)

No. Date.

Dawson arkose is a name applied by this writer to the lower part of rocks formerly called Monument Creek. He states that "it is evident that in the Castle Rock region the Dawson arkose, together with its associated unconformities, represents the time between the Laramie and the Oligocene . . . the lower part of the Dawson arkose seems to pass along the strike into the Arapahoe and Denver formations; that the Dawson and Arapahoe cannot be separated lithologically, even at the type locality of the Arapahoe on the bluffs of Willow Creek; and that the Denver and Dawson apparently merge into each other." It is further stated that "the evidence [of certain vertebrates] implies the correlation of the lower part of the Monument Creek of Hayden [the lower part of the Dawson arkose] and the 'post-Laramie' of the Denver Basin [the Arapahoe and Denver formations]. The evidence of the plants is corroborative, for . . . Doctor Knowlton states that the leaves from the lower part of the Dawson arkose . . . are undoubtedly Denver in age." From these statements it is evident that the Dawson is regarded as Tertiary in age and that the Arapahoe and Denver formations also are Tertiary.

PRELIMINARY MAP OF PLEISTOCENE DEPOSITS OF PORTIONS OF GLACIER NATIONAL PARK AND BLACKFOOT INDIAN RESERVATION, MONTANA

(By Wm. C. Alden, assisted by J. E. Thomas)

High mountain area dissected by many deep glaciated valleys, with small existing glaciers.

Deposits of mountain glaciers of Wisconsin stage in valleys and on the plain east of the mountain front (mapping not complete).

Deposits of the Keewatin ice-sheet of the Wisconsin stage of glaciation.

Deposits of pre-Wisconsin glacial drift capping high flat-topped ridges of Cretaceous shale and sandstone—that is, lying on remnants of the Blackfoot peneplain (mapping not complete).

(Boundaries of drift of Saint Mary and Keewatin glaciers from F. H. H. Calhoun and E. Stebinger.)

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PRE-WISCONSIN GLACIAL DRIFT IN THE REGION OF GLACIER NATIONAL PARK, MONTANA[1]

BY WILLIAM C. ALDEN

(*Read before the Society December 28, 1911*)

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Existing Glaciers and Wisconsin Glaciation

During the field season of 1911 the writer had the pleasure of being associated with Mr. M. R. Campbell, Dr. T. W. Stanton, Mr. J. R. Hoats, and Mr. J. Elmer Thomas, of the U. S. Geological Survey, in initiating a geological survey of Glacier National Park, Montana, his particular assignment being the study of past and present glaciation and associated phenomena[2] (plate 37).

[1] Manuscript received by the Secretary of the Society April 15, 1912.

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[2] It should be stated that while the surveying done by this party during the past field season was carried on in detail wherever there was opportunity, the work as a whole was rather in the nature of a general reconnaissance, the object being to get the various problems in hand, but not to complete the investigation of any of them. In some respects, therefore, the conclusions set forth in this paper are to be considered as tentative and subject to such modification as further studies make necessary.

The topography of Glacier Park and of the western part of the Blackfeet Indian reservation, including the features here described, is delineated on the new topographic map of the park and, excepting the southern part, on the Browning, Chief Mountain, and Kintla Lake topographic sheets.

There are in the cirques at the heads of the valleys, high up on the flanks of the mountains in the heart of the Lewis Range, one hundred or more existing glaciers, ranging in size from those a few square rods in extent to ice fields of 2 or 3 miles area. Besides the cirques in which these glaciers lie, there are a multitude of glacial amphitheaters, in many of which are beautiful lakes, but in which glaciers do not now exist. These cirques are among the most wonderful phenomena of the park. From these cirques broad-bottomed, steep-walled, U-shaped valleys extend to the mountain front, showing in their contours and in the deposits of drift which they contain the effects of a former much more numerous existence and much greater extension of the valley glaciers. Numerous trunk glaciers, fed by a multitude of tributary glaciers, extended eastward and westward to and beyond the mountain front. The deposits of those extending out on the plains to the east of the range have been described by Mr. F. H. H. Calhoun in professional paper number 50 of the United States Geological Survey, entitled "The Montana Lobe of the Keewatin Ice-sheet." Ice discharging from the mountain valleys tributary to Two Medicine River is described as having coalesced and spread over the plain as "a large piedmont glacier which extended about 50 miles from the main divide and which in its widest part was over 30 miles across.[3] This is referred to as the "Blackfoot Glacier," a somewhat infelicitous designation, inasmuch as the largest of the existing glaciers in the park, but 10 miles distant from the head of Two Medicine Valley at the nearest point, bears the name "Blackfeet." A better name for the extinct glacier, which headed principally in valleys tributary to Two Medicine River, would be the "Two Medicine Glacier." Perhaps I may be pardoned if on account of this conflict in nomenclature I make this substitution. At the head of Lower Two Medicine Lake the ice in this valley had a thickness of about 1,000 feet.

Ice in the valleys of the north and south forks of Cut Bank Creek, the next stream north of the Two Medicine, coalesced several miles from the mountain front forming the Cut Bank glacier, which extended about 18 miles from the Continental Divide. Two small lobes of the glacier spilled northward through sags in the crest of Milk River Ridge[4] into

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[3] Loc. cit., p. 18.

[4] There seems to be some confusion of usage of names applied to the several ridges of Cretaceous sandstone and shale east of the mountain front. Mr. Calhoun, in his paper, refers to the ridge east of Lower Saint Mary Lake as "Milk River Ridge," and to the ridge north of Lower Two Medicine Lake as "Cutbank Ridge." On the topographic maps, however, the name "Saint Mary Ridge" is applied to the ridge east of Lower Saint Mary Lake, and the name "Milk River Ridge" to the ridge north of North Fork of Cutbank Creek. This latter usage, which appears to be the common one, will be followed in the present paper. The name "Cut Bank Ridge" will be applied to the ridge between

Milk River Valley, where, however, they had but relatively small extension. The relations of these spillways show that the thickness of ice in the North Fork Valley must have been about 1,000 feet just east of the mountain front.

Saint Mary River Valley and its tributaries were occupied with ice which formed a glacier of large size, extending northward across the 49th parallel. The main stream heading, where now lie the Blackfeet and Red Eagle glaciers, thus had a length of about 35 miles south of the international boundary, and extended an undetermined distance northward over the plain of southern Alberta. The main tributaries occupied the valleys of Red Eagle, Boulder, Swiftcurrent, and Kennedy creeks. Glacial drift was found on the slope of Singleshot Mountain up to 1,275 feet above the foot of Upper Saint Mary Lake, and the position of the lateral moraine just below the crest of Saint Mary Ridge on the east shows that the surface of the glacier stood about 1,350 feet above the level of Lower Saint Mary Lake.

West of Chief Mountain is Belly River Valley. Heading at the Continental Divide, 10 to 12 miles south of the 49th parallel, where are now Chaney and neighboring glaciers, a considerable stream of ice extended northward onto the plain of southern Alberta. Still farther west a large glacier issued from the valley west of the north end of the Lewis Range, in which is now Waterton Lake. The extent of this stream of ice in Alberta was not determined, but its depth is known to have been considerable, for ledges smoothed and striated by this glacier were found on the mountain slope about 1,700 feet above the head of Waterton Lake.

The fresh and unmodified character of all the phenomena resulting from this extensive mountain glaciation indicates that it is probably to be correlated with the last of the great extensions of the Keewatin ice-sheet, that of the Wisconsin stage of glaciation, and this correlation is assumed in the present discussion. The purpose of this present paper is not, however, the discussion of this later well known glaciation, but the description of certain deposits which indicate that the Lewis and Livingston ranges were subjected to glaciation at another and much earlier stage.

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the north and south forks of Cut Bank Creek, and the name "Two Medicine Ridge" to the ridge north of Lower Two Medicine Lake. The name "Point Mt.," which is printed on the map on the ridge between Swiftcurrent and Boulder creeks, is applied by the people of the region to the mountain to the southwest for which the map shows the name "Altyn Mt." It is proposed to transfer the name "Point Mt." to this peak and to designate the ridge between Swiftcurrent and Boulder creeks as "Boulder Ridge." The ridge north of Swiftcurrent Creek will be referred to as "Swiftcurrent Ridge." The name "Kennedy Ridge" will be applied to the ridge with two crests north of North Fork of Kennedy Creek.

Topography of the Plain

The terminal moraine of the Keewatin ice-sheet was traced northward across the Cut Bank quadrangle to the international boundary, in longitude 112 degrees 20 minutes west, by Mr. Calhoun[5] in 1902. From this point the margin of the Keewatin drift trends westward, in part north and in part south of the 49th parallel, to Waterton River. Going westward from the terminal moraine across the Blackfeet Indian reservation, one finds the area characterized by the topography which is delineated on the Cut Bank, Blackfoot, and Browning topographic sheets, and which has been described by Willis[6] and Calhoun. It is a great treeless plain, in places nearly flat, but mostly rolling to hilly, rising gradually toward the mountains. Standing above the plain here and there in the eastern half of the reservation are butte-like eminences or small elevated plateaus and elongated ridges, with abrupt, incised marginal slopes. These have reliefs of several hundred feet above the valley bottoms. Farther west such elevated tracts gradually coalesce into broader plateaus or larger ridges which are particularly characterized by smooth, nearly flat surfaces. Approaching the mountain front, bulky ridges stand at either side of the principal valleys heading in the range and lead directly up to the bases of the bold salient mountains which guard the portals to the park. Adjacent to the mountain front these ridges attain elevations ranging from 5,900 to 6,400 feet above sealevel and stand 800 to 1,600 feet above the intervening valley bottoms. Taken together, the flat-topped ridges and plateaus have the appearance of being remnants of a continuous high-level plain which once sloped gradually eastward from the base of the mountains, but which has been so reduced by long-continued stream erosion that but a small part of the original surface now remains.

Describing these features in his paper on the "Stratigraphy and structure of the Lewis and Livingston ranges," Mr. Bailey Willis writes:

"The highest surfaces of the plains are limited in extent, constituting according to field estimate not more than one-fiftieth of the total area. Nevertheless their profiles fall into a uniform line that represents an ancient plain, due to the erosion of the Cretaceous shales and sandstones of unequal hardness. The extent and uniformity of the plain are very marked, and it is the initial physiographic fact of the region. It is herewith designated the Blackfoot plain, after the Indian tribe whose name is associated with the region. On this ancient surface there is a widely distributed thin layer of gravel which is supposed to antedate the Pleistocene deposits."

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[5] Op. cit., p. 22.

[6] Bailey Willis: Stratigraphy and structure of the Lewis and Livingston ranges, Montana. Bull. Geol. Soc. America, vol. 13, 1902, p. 310.

FIGURE 1.—TWO MEDICINE RIDGE OF UPTURNED AND BEVELED CRETACEOUS SANDSTONE

In this part capped with coarse "quartzite gravel" and farther west with pre-Wisconsin glacial drift. Moraine of Two Medicine glacier of Wisconsin stage in the foreground.

FIGURE 2.—PRE-WISCONSIN GLACIAL TILL, LARGELY CEMENTED TO TILLITE CONGLOMERATE EXPOSED AT WEST END OF UPPER PART OF TWO MEDICINE RIDGE

PRE-WISCONSIN GLACIAL MATERIAL IN MONTANA

Inasmuch as the investigations of the past summer were confined principally to observations in and adjacent to the mountains themselves, a thorough examination was not made of all these elevated tracts on the plain, and the deposits lying on them were not seen far from the mountains. The results of the observations that were made, however, are so significant that a preliminary statement concerning them seems warranted at this time.

Beginning at the south, a brief description will be presented of the character and relations of the deposits on the several high ridges examined by Mr. Thomas and the writer in the belt near the mountains.

Deposits on Two Medicine Ridge

Issuing from the mountains about 7 miles northwest of the village of Midvale, Two Medicine River swings to the southeastward and traverses the plain in a sharply cut, trenchlike valley. The lower lake lies about 800 feet below the level of the rolling drift-covered plain on the east. Going northward from Midvale across this plain one finds well marked, though mildly developed sag-and-swell moraïnal topography set with numerous little ponds. This marks the marginal moraine of the Two Medicine glacier of the Wisconsin stage (plate 39, figure 1). It ends at the north along a fairly definite line near the foot of the south slope of a long flat-topped sandstone ridge, part of (plate 38, figure 1) "Two Medicine Ridge." To the east the ice extended through the gap in the sandstone ridge, which is traversed by the Great Northern Railroad and spread over the lower land toward Browning. South of the railway the glacier overtopped the ridge and left later glacial drift thereon. Through a length of 3½ miles northwest of the railway the ridge was not surmounted by the later ice-sheet. That part of the ridge shown in plate 38, figure 1, has a relief of about 200 feet. Ascending the abrupt slope, the top is found to be notably flat excepting where cut by a ravine which partially divides the ridge. It rises gradually westward from 5,300 to 5,600 feet above the sea. This plateau surface, which is a remnant of the Blackfoot peneplain, is beveled across the edges of the Cretaceous sandstone, which at one point noted has a dip of 42 degrees toward the southwest. Capping the ridge is a thin deposit consisting of gravel ranging in size from fine to boulders 1½ feet long. The stones are partly well rounded, but mostly subangular. They are principally of quartzite, white, yellowish, banded pink, and red, and with these are pebbles of maroon argillite, green argillite, and diorite, named in the order of relative abundance. All these rocks are from the pre-Cambrian formations of the mountains to the west, and the same kinds of pebbles

and boulders comprise the coarse material of the later glacial drift on the adjacent plain below. The only constituents of the later drift not found on this part of the ridge were limestone and a quartzite conglomerate containing pebbles of black chert, which occurs principally in the drift somewhat farther south and is from ledges exposed in the pass traversed by the railway and provisionally referred by Doctor Stanton to the Lower Cretaceous. Fragments of this conglomerate may never have been deposited on this upland tract, and the limestone if deposited may have been removed by solution. Careful examination of the pebbles failed to reveal any showing glacial striation.

Going westward, the undulating drift plain gradually rises, and northeast of Lower Two Medicine Lake for about a mile the later drift overlaps the higher plain. Crossing this interval, the sandstone ridge rises above the later drift plain, increasing rapidly in height, until one stands on a flat-topped mesa with an elevation of 6,200 feet above the sea, a height of 400 feet above the margin of the later drift, a relief of about 1,350 feet above the lake. Here there is a somewhat thicker deposit of the same material and among the pebbles a few of limestone were noted. This high tract has a length of about half a mile. Beyond this there is a sharp drop in the crest of 100 feet or more. West of this sag the crest rises again until the 6,200-foot level is attained.

On the day following that on which this part of the ridge was examined, approaching the ridge from the northeast, we climbed 1,200 feet from the South Fork of Cut Bank Creek, over slopes of upturned and folded sandstone, till we reached the flat top of the western part of Two Medicine Ridge. On this top were found coarse gravels and boulders of the same character as noted farther east. Many of the stones, however, were much larger, some being boulders 8 feet in length. The deposit seems to thicken toward Two Medicine Valley, and at the southwest extremity of the half-mile-wide mesa top a fresh scarp, due to slumping of the underlying Cretaceous, exposed 150 feet of the material. Here the deposit is typical glacial till (figure 2, plate 38). There is no assortment or stratification, the stones, which range in size from small pebbles to boulders 8 feet in length, being heterogeneously mixed and imbedded in a matrix of reddish clay. A large part of the deposit is cemented by calcium carbonate to hard, tillite conglomerate. This stands with vertical face and as towers 15 to 25 feet in height. Some of the stones are well rounded, but a large part of the pebbles and boulders are subangular, facetted, and beautifully striated (figure 2, plate 39). The material is wholly derived from the mountains, being of the same lithologic character as the gravels found on the ridge farther east. Lime-

FIGURE 1.—MORAINE OF THE TWO MEDICINE GLACIER OF THE WISCONSIN STAGE AT A POINT 5 MILES NORTHEAST OF MIDVALE, MONTANA

FIGURE 2.—GLACIATED BOULDERS IN PRE-WISCONSIN GLACIAL TILL EXPOSED AT WEST END OF TWO MEDICINE RIDGE

PRE-WISCONSIN GLACIAL MATERIAL IN MONTANA

stones are rare among the stones scattered over the mesa top and also in the upper part of the 150-foot section. Farther down the slope, however, they become more numerous and show less effects of weathering. It is probable that the calcareous cement of the conglomerate was derived from solution of the limestones in the upper part of the deposit. This exposure faces the mountain slope at a distance of something over a mile. Between the two the ridge has been lowered and narrowed by erosion. This lower part is densely timbered and was not examined. From this narrowed divide the valley between the high mesa and the much higher mountain slope deepens rapidly northward to a level 1,000 feet below the top of the former. The composition of the deposit, its topographic situation relative to the mountains, to the present drainage lines and to the deposits made by the glaciers of the Wisconsin stage, the modification by weathering, and the cementation to a heavy bed of conglomerate all indicate that we have here a glacial deposit of relatively great age. If all the dissection of the Blackfoot peneplain was accomplished in the interval between deposition of the high level and the low level drifts, the earlier glacial extension antedated the Wisconsin glaciation by a very long time.

North of this drift-capped ridge are numerous much lower hills and ridges of sandstone and shale. On one of those examined a few pebbles of quartzite and diorite were found, but on the others there was no evidence of this older drift. Among these hills flow tributaries of South Fork of Cut Bank Creek. One of these, Lake Creek, heads in glacial cirques in the mountains, and, stretching eastward on either side of the valley, are the finely developed moraines of a glacier of the Wisconsin stage.. At its greatest extension Lake Creek glacier had a length of about 10 miles. At points equally distant from the mountain front the crests of these moraines of Lake Creek glacier stand 500 feet lower than the top of the high drift-capped mesa, and the bed of the stream between them is 300 feet still lower.

Deposits on Cut Bank Ridge

Between the South and North forks of Cut Bank Creek is a ridge of Cretaceous shale whose crest 1 mile from the mountain front has an elevation 6,300 feet above the sea. Standing on this crest one looks down 1,000 feet to the stream on the south and 1,200 feet to bottom of the valley on the north. Both slopes are steep, that on the north being particularly precipitous, that on the south much less so. Shale is exposed to within 100 feet of the top near the west end of the highest part of the

crest. Here there is an abrupt drop in the crest line, and from this point to the mountain the crest is narrow, lower, and composed of shale. The highest part of the ridge is capped with till and gravelly drift, which is exposed at several points in fresh scarps due to landslides. The lithological composition is the same as on Two Medicine Ridge and many of the green argillite fragments show glacial striations. This rock is very dense, fine grained, and so difficultly soluble as scarcely to be etched at all even after very long exposure to the weather. Some of the limestone blocks are 6 to 8 feet in length. The top of this ridge is broad, smooth, and gently sloping. The north slope is heavily timbered and there has been much slumping of the drift on the underlying shale, so that the upper limit reached by the North Fork glacier during the later extension of the ice has not been accurately determined. Judging from the condition on the opposite side of the valley, the surface of the later ice was at least 200 feet below the top of this ridge.

Between 4 and 5 miles east of the mountain the crest drops 300 or 400 feet to a sag. Through this sag the ice of the North Fork glacier of the Wisconsin stage appears to have extended nearly or quite to contact with that of the South Fork glacier. Beyond the sag the crest rises again 200 to 300 feet, maintains its height for about a mile, and again drops to a much lower level, over which the later ice spread morainal deposits. Two miles farther southeast the ridge, here of sandstone, rises again above the later drift and extends thence eastward with even, flat top, 2 miles to the point where it is cut by the post-glacial gorge of the South Fork of Cut Bank Creek. East of this creek the ridge continues toward Browning, but is still lower and was overridden by the later ice. Both the isolated mesa-like parts of the ridge are capped with coarse gravel, largely quartzite, evidently to be correlated with the drift farther west and on Two Medicine Ridge, although here no till and no striated pebbles were observed.

Deposits on Milk River Ridge

On the north side of the valley of North Fork of Cut Bank Creek is another great ridge of Cretaceous shales and sandstones left from the erosion of the Blackfoot peneplain. This is known as Milk River Ridge from the fact that tributaries of that stream head on its north slope. Down the great trough between Milk River and Cut Bank ridges Cut Bank glacier extended at the Wisconsin stage of glaciation, attaining a length of 12 miles east of the mountain front. Climbing 1,600 feet from the valley bottom to the point where Milk River Ridge joins the mountain front, one finds the deposits much disturbed by landslides, but it

looks as though the ice emerging from the mountain valley extended this high up on the slopes. Overtopping the proximal end of Milk River Ridge, the glacier appears to have spilled across the crest, extending a small lobe about 2 miles northeastward down the slope on the north. Perhaps this was assisted somewhat by ice descending from a fine big cirque in the east slope of the mountain. Two well formed lateral moraines are seen curving northward through the east side of a sag in the crest of the ridge. Crossing this sag and climbing to the high flat top, which here stands at an elevation of 6,100 feet above the sea, it appears that the last ice just overtopped the north slope at the west end of this part of the ridge and left there a small marginal ridge of drift. This may be traced eastward about three-quarters of a mile on the top of the ridge; it then drops down to a lower level and lies along the slope 100 feet or so below the top. On the high flat part of the top of the eminence, beneath and beyond the little marginal ridge, is a deposit of coarse gravelly drift yellowed with age and in which no limestone was observed, although a massive bed of limestone is exposed in the mountain slope to the west, and derived fragments are plentiful in the later drift. It does, however, contain striated pebbles. The character and relations of this deposit show that there is here another remnant of the old high level drift. At the east end of this mesa an abrupt slope drops down about 500 feet to a second sag in the crest 1¼ miles in width. This broad sag in the crest afforded another spillway for Cut Bank glacier, and through this a tongue of ice extended northward a distance of 3 miles into the Milk River Basin, spreading out on the lower ground as a lobe over 2 miles in width. This small lobe is designated the Milk River glacier by Mr. Calhoun.[7]

Crossing this second sag and climbing about 350 feet up a steep slope one reaches the top of the main part of Milk River Ridge. From the high west end one looks out over an extensive and remarkably smooth plateau, sloping toward the northeast. In the first 1½ miles the surface declines 300 feet; beyond this there is a fairly uniform slope of nearly 80 feet per mile for 5½ miles, the farthest distance to which the tract was traversed by the writer. Farther east deepening ravines cut the plateau into digitate, flat-topped ridges, and these in turn give place to successively lower separated buttes. This elevated plateau is the best preserved and most typical remnant of Mr. Willis's Blackfoot peneplain seen by the writer.

The drift of the Wisconsin stage extends nearly to the top of the head of the high level plain, reaching an elevation of 5,800 feet above the sea

[7] Op. cit., p. 20.

and piling up in sharp knolls and ridges. This drift, however, overlaps but little if any of the upper plain. Eastward from this point the margin of the later drift gradually descends the eroded south slope until in about 5 miles it lies 300 feet or more below the upland at the point where the marginal moraine of the valley glacier swings off to the southward across the valley plain.

Mr. Calhoun[8] also determined that the ice, though nearly filling the valley of the North Fork of Cut Bank Creek, "did not spread over the plateau to the north."

Underlying this extensive high level plain is a yellowish to brownish oxidized gravelly deposit like that described above, consisting principally of quartzite with much green and red argillite, diorite, and some limestone. The stones are subangular to rounded, and it seemed to me there was no notable decrease in size with increasing distance from the mountains. Numerous boulders 1 to 1½ feet in diameter are found 2 to 3 miles from the head of this plain and 8 to 10 miles from the mountains, the source of all the material. That exposed in a ravine in the northeast quarter of section 12, township 33 north, range 13 west, consisted of clay, pebbles, and boulders mixed as in glacial till. In the southeast quarter of this section 100 feet of unassorted material was found, and in the northwest quarter of section 6, township 33 north, range 12 west, a thickness of 150 feet was observed. Here and elsewhere glaciated pebbles were found, though these are nowhere abundant and consist mostly of the green, quartzitic argillite. Such striated erratics were found in the sides of the valley of Arnold Creek as far out on this plain as our traverse was extended.

It is the writer's understanding that the deposit capping this Milk River Ridge is included with what has been described as the "quartzite gravels" and has been regarded as pre-glacial in time of deposition. Where seen by the writer, however, this contains well striated pebbles and has the general characteristics of glacial drift. It evidently should be correlated with the deposit of Two Medicine Ridge as pre-Wisconsin glacial drift.

Deposits on Saint Mary Ridge

Emerging from the mountains between the bold salients known as Divide Mountain and Singleshot Mountain, the waters of Saint Mary River flow in a general direction nearly due north through the lower lake and beyond until they cross the international boundary. Bordering the

[8] Loc. cit.

lower lake and the lower part of the upper lake on the east is an undulating tract about a mile in width composed of small hills and ridges of shale mantled with drift and standing 100 to 300 feet above the lake levels. From this a steep slope, most of which is heavily timbered, rises to the crest of a broad ridge known as Saint Mary Ridge. The crest of this ridge gradually lowers in elevation from south to north. It is highest between 2 and 3 miles north of Divide Mountain, there standing about 6,100 feet above sealevel. In the interval between this highest part and the mountain there is a broad sag in the crest line where the top of the ridge is 300 feet lower. Where highest the top of Saint Mary Ridge stands over 1,600 feet above the level of the upper lake. From this highest part the northward decline carries the crest line down to a level which, east of the foot of the lower lake, between 9 and 10 miles to the northward, is about 1,100 feet above the water in this lake and 5,500 feet above tidewater. Duck Lake lies in a big sag in the upland, so that the crest of the ridge may be said to curve eastward on the south side of the lake. The top of Saint Mary Ridge is broad and smooth. From this the plain slopes gradually to the eastward. Much of this surface has been lowered by erosion by the headwaters of tributaries of Milk River, but in the interstream areas the higher tracts still represent the Blackfoot peneplain.

Beyond the broad sag, in which lies Duck Lake, the Hudson Bay divide continues as a broad high ridge similar to and really a part of Saint Mary Ridge. This part of the ridge, which consists of Cretaceous sandstones and shales, has not been examined. The ridge east of Saint Mary Lake has not been thoroughly examined, but what was seen by Mr. Thomas and the writer is significant in connection with this question of pre-Wisconsin glaciation.

On the steep west slope of Saint Mary Ridge there has been considerable landsliding on the shale, which probably forms the bulk of the ridge. At a few places near the top of the slope this slumping has produced fresh scarps, giving excellent exposures of the material capping the ridge. Following the trail southeastward from the foot of Upper Saint Mary Lake for about 1½ miles and then climbing the wooded slope, we reached one of these scarps between 1,100 and 1,400 feet above the lake. The exposure has a height of nearly 300 feet and a length of 500 feet or more. The upper 30 to 50 feet (A) of the section is grayish glacial till, in which the pebbles and boulders are of red and green argillite, quartzite, gray siliceous limestone from the Siyeh formation, diorite, and some buff limestone from the Altyn formation. It looks as though most of the Altyn limestone pebbles had been removed by solution and frag-

ments of the Siyeh limestone are deeply etched. Beneath this is (B) a 10 to 15 foot band, where the till is oxidized to an orange or yellowish tint. In this is more of the yellow oxidized limestone, some of the fragments of which are thoroughly rotted. Underlying this zone and forming the greater part of the section is (C) reddish till cemented by calcium carbonate to a hard conglomerate which projects from the slope as ledges. Most of the pebbles and boulders in this have fresh glaciated surfaces, but some of the diorites are disintegrating; many of the buff limestones are etched by solution and some have been removed, leaving only a yellowish powder in the cavities. The reddish tint is due to the large amount of red argillite. The calcium carbonate cement was probably derived by percolating waters from the solution of limestone fragments in the upper part of the section. It is the projecting ledges of conglomerate which give to the deposit, as seen from the valley below, the appearance of stratification. Close examination reveals no assortment of the material or bedding. No fragments of rock were noted other than such as are derived from the mountains. About 250 feet of drift was seen, but the base was not exposed. About half a mile farther south a second similar exposure of this was examined. Here the yellow band (B) was not so noticeable, but other evidences of weathering and cementation are the same. Four miles north of this later scarp a third exposure was examined by Mr. Thomas. He reports 250 feet of drift of much the same composition as noted above. No limestone was noted at the top, though blocks of Siyeh limestone were seen in the conglomerate, which extends to within 5 or 10 feet of the grassed top.

From the material exposed at these several points it is apparent that the capping of Saint Mary Ridge is a deposit of old drift identical in character with the old drift on Two Medicine Ridge excepting for the presence here of fragments of Siyeh limestone. Owing to the thick woods and the large amount of landsliding on the southern half of the steep slope, the upper limit reached by the Saint Mary glacier of the Wisconsin stage could not be determined there. Farther north, about a mile south of the point where the ridge is crossed by the Babb-Browning road, a small but definite morainal ridge begins to be developed somewhat below the crest of the smoothly curved top of the big ridge. This small drift ridge, which is evidently the lateral moraine of Saint Mary glacier, was traversed about 3 miles and found to be strengthening toward the north. South of Duck Lake this curves eastward with the crest of the big ridge. This moraine carries plentiful blocks of limestone, but on the smooth broad top to the east little else than quartzite pebbles were noted. As determined from the sections described, these "quartzite

gravels" represent the insoluble weathered residuals at the top of the older drift. Taking everything into consideration, it is clear that the heavy drift forming the capping of Saint Mary Ridge can not be referred to the last Saint Mary glacier, although that ice-stream so far filled the valley as to overtop the high slope of the ridge east of the lower lake.

Deposits on Ridge west of Lower Saint Mary Lake

On the west side of Lower Saint Mary Lake a correlative, but somewhat smaller ridge of Cretaceous shale and sandstone lies between the lake on the east and Flattop Mountain and Boulder Creek Valley on the west. The crest of the ridge is narrow and serrate, consisting of a row of sharp hills extending north-south on the line between sections 16 and 17, township 35 north, range 14 west. These peaks stand 5,700 to 5,900 feet above sealevel, 1,200 to 1,400 feet above the lake, and 500 to 700 feet above Boulder Creek. There is no very good exposure, but the material seen on the surfaces of the knobs is like that of the drift described above. Mr. Campbell reported that he found tillite conglomerate on top of one of the hills. It is probable that this is a remnant of the pre-Wisconsin drift. The surface of the ridge surrounding the line of hills is marked by low swells and sags, the result of later drift deposition or of landsliding or a combination of both.

Deposits on Boulder Ridge

On the crest of the Cretaceous ridge between Boulder and Swiftcurrent creeks is a heavy deposit of glacial till which appears to be 200 feet or more in thickness. This is exposed in fresh scarps due to slumping at two or three places at the tops of the north and south slopes. The pebbles and boulders in the reddish till are of limestone, red and green argillite, quartzite and diorite, and are well facetted and striated. Ledges of tillite conglomerate due to cementation protrude from the drift slope, but there is no notable evidence of weathering and limestone pebbles are present nearly or quite to the top. The top of this highest part of Boulder Ridge is notably flat, like the crest of Two Medicine Ridge, and has a length of about 2 miles. In this length the elevation increases southwestward toward the mountain from about 6,100 to 6,300 feet above tidewater. It thus stands 600 to 800 feet above Boulder Creek on the south and 1,400 to 1,600 feet above Sherburne Lakes in Swiftcurrent Valley on the north. At the southwest end of this flat top a short sharp ridge rises to an elevation of 6,400 feet above the sea. The rise does not

continue to the front of Point Mountain, but after reaching this high altitude the crest drops abruptly to a notch 200 feet or more in depth, beyond which it again rises to Point Mountain. This sharp, highest part of the crest of Boulder Ridge consists of chipstone of limestone, white quartzite, and red and green argillite, such as compose Point Mountain. No fragments of diorite were noted. The material does not look like glacial drift but like talus, and its character and relation leads to the suggestion that here is the last remnant of a disintegrated salient of Point Mountain, which at the time of the deposition of this high level drift extended 1¼ miles farther to the northwestward than it does at present. The material is from the pre-Cambrian formations, which in the nearest part of Point Mountain lie at elevations more than 800 feet higher than does this remnant. This relationship indicates either that the pre-Cambrian rock of this remnant was let down from a higher elevation by gradual slumping or washing away of the underlying Cretaceous shale, or that, owing to a slight anticlinal fold, it originally stood lower at this point than it does in Point Mountain, 1¼ miles away, where the rock is now inclined upward in the direction of the remnant in question. Owing to similarity in component material of the older and younger drift and to the slumped and wooded condition of the slopes, it is difficult to determine just how high on the flanks of Boulder Ridge the ice of Boulder Creek and Swiftcurrent glaciers extended at the Wisconsin stage of glaciation. It seems clear, however, that the later ice did not overtop the ridge, and that the drift capping the crest of the ridge is that of a much earlier stage of glaciation.

Deposits on Swiftcurrent Ridge

The companion ridge to that just described stands between Swiftcurrent Valley on the south and South Fork of Kennedy Creek on the north. A subordinate part of this ridge extends northward at right angles to the main ridge from Swiftcurrent Valley and forms the divide between Saint Mary Valley on the east and South Fork of Kennedy Creek on the west. The subordinate ridge, which rises 650 to 850 feet above the bottom of the valley on the east, appears to have been overtopped by Saint Mary glacier of the Wisconsin stage, inasmuch as morainal deposits are found along its crest. The summit of the main ridge, which trends in a general east-west direction, appears not to have been overtopped by the later ice moving down the valleys of either Swiftcurrent Creek or South Fork of Kennedy Creek. For 2½ miles the top of this ridge is very even (plate 40, figure 1), with a width of 90 to 120

FIGURE 1.—FLAT TOP OF SWIFTCURRENT RIDGE, A REMNANT OF THE BLACKFOOT PENEPLAIN, CAPPED WITH PRE-WISCONSIN GLACIAL DRIFT

Looking northwestward to Yellow Mountain in background, Appekunny Mountain at left, and Chief Mountain at right

FIGURE 2.—MESA OF "KENNEDY GRAVEL," PROBABLY PRE-WISCONSIN GLACIAL DRIFT, 5 MILES EAST OF CHIEF MOUNTAIN

(Photo by Bailey Willis)

PRE-WISCONSIN GLACIAL MATERIAL IN MONTANA

rods. It gradually increases in elevation from about 5,800 feet above sealevel at the east to 6,000 feet at the west, so that it stands about 1,150 to 1,250 feet above Swiftcurrent Creek on the south. From this top steep slopes decline on either hand. At the top of the south slope is an abrupt scarp due to landsliding. This has a height of 200 to 300 feet, and below is an uneven slope marked by swells and sags and numerous small lakelets. This slope resembles morainal topography, but is probably principally due to slumping of the drift over the soft Cretaceous shale. Two hundred feet or more of glacial till is exposed in the clean scarp faces at the top of the slope. This drift is of the same composition and appearance as that on the ridge across the valley to the south excepting that here, in addition to the other ingredients, fragments of Siyeh limestone and amygdaloidal trap rock are found. The latter is present in the mountains at the head of Swiftcurrent Valley. Many of the pebbles and boulders are beautifully striated. Blocks of the tillite conglomerate were seen, but no ledges clearly in place. Part of the diorite boulders are considerably weathered so as to be exfoliating shells half an inch thick, and some of the limestones in the upper part are etched but not removed by solution. The drift on the whole looks fresh and shows but little modification by weathering.

At the west end of the high tract just described the ridge narrows and the crest is broken by a sag about 1¼ miles in length. This part is crossed by the boundary between the Blackfeet Indian reservation and Glacier Park. Here the drift capping has been removed and Cretaceous shale is exposed at intervals. Beyond this the crest again rises and a narrow remnant of the old drift remains. This part of the ridge was examined by Mr. Thomas, but not seen by the writer. Mr. Thomas reports a notched flat crest rising from 6,100 to 6,200 feet above the sea, and scarps giving good exposures of 200 feet of glacial drift like that forming the top of the ridge farther east, with ledges of tillite conglomerate in place. On the surface boulders of diorite and amygdaloidal trap are conspicuous, some being 4 to 6 feet in length. The drift was observed in place to within a few hundred feet of the pre-Cambrian Altyn limestone in the east end of Appekunny Mountain. West of a notch there is an abrupt rise to a bench at 6,300 feet above the sea. This is cut in solid limestone and extends for a short distance about the north side of the point of the mountain. On this bench no drift was found. The top of the drift stands nearly 1,500 feet above Swiftcurrent Creek on the south and 800 feet above South Fork of Kennedy Creek on the north. From the topographic relations and the presence of the tillite conglomerate, there is little room for doubt that this high level

drift is to be correlated with the other deposits described as having been laid down by ice during a pre-Wisconsin extension of the mountain glaciers.

Deposits on Kennedy Ridge

North of North Fork of Kennedy Creek in the area east of Chief Mountain is a hilly tract underlain by Cretaceous sandstones. A part of this at least was covered by ice at the last stage of glaciation, but little of it was examined during the past summer. Rising above the general level of this tract, just north of Kennedy Creek, is a small, abrupt, flat-topped mesa having an elevation 5,800 feet above tide and 900 feet above the stream on the south (figure 2, plate 40). This was described by Mr. Willis in his paper on the Lewis and Livingston Ranges[9] as "the typical occurrence of the Kennedy gravels." The slopes of this mesa are abrupt scarps due to landslides, and in places these scarp faces are bare of vegetation and give good exposures of the component material, 100 feet or more in height. This material is coarse cobblestone gravel and small boulders. A large part of the stones are subangular and facetted and some of it is well rounded. No evidence of assortment or bedding was noted and, to the writer, the aspect was rather that of gravelly glacial drift than of stream gravels. Moreover, careful search yielded numerous pebbles carrying striations which, if not due to glaciation, are certainly identical in character with such as were produced by glaciation. The stones, which are wholly pre-Cambrian rock from the mountains, consist principally of buff limestone and quartzitic material from the Altyn formation, and with this is a subordinate amount of red and green argillite. Striations were found only on pieces of the greenish dense quartzitic argillite. The surfaces of other pebbles had been sufficiently etched and roughened by weathering to remove striations if such were present. The ridge stands so high and is so narrow and so exposed on all sides that conditions particularly favor the surficial modifications of the material by the various agencies of weathering.

Mr. Willis reports[10] that Mr. George I. Finlay, who examined the deposit, did not find striated pebbles. Concerning their interpretation, he writes as follows:

"The constituent materials, the forms of the boulders and pebbles, the obscure stratification, the topographic form, and the position of the mesa, all characterize this occurrence as a remnant of an alluvial cone of Kennedy

[9] Op. cit., pp. 328-330.
[10] Op. cit., pp. 328-330.

Creek. No earlier record has been detected in the history of that stream. Since that date, however, the valley has been cut down 900 feet, a glacial epoch has intervened, and the channel has recently been re-excavated and sunk deeper in the subterrane.

"Certain tabular drift surfaces between Swift Current and South Kennedy creeks and on the northern slope of Yellow Mountain are probably not of the Kennedy formation, but are outwash plains beyond moraines. Gravel mesas, that are correlative with the Kennedy and may be included under the formation name, occur in Canada, one lying 6 to 8 miles north by west from Chief Mountain and east of Belly River; another, a group of three hills, occurring east of lower Waterton Lake, a few miles north of the boundary. The basis of correlation in these two cases is general form, altitude, and constitution of the masses, which were not, however, examined in detail."

The character and relations of the deposit on the ridge between Swiftcurrent and South Kennedy creeks have already been described. The mesas in southern Alberta on the east sides of Belly River and Waterton Lake were seen but were not examined. Neither was the tabular surface on the slope of Yellow Mountain examined.

In discussing the relations of the Kennedy gravel mesa, Mr. Willis refers to it as "isolated and equalled in height among the outlying hills only by a ridge of Cretaceous sandstone about 100 feet higher and 2 miles west of it." After examining the Kennedy gravel mesa, Mr. Thomas and I crossed the intervening sag, which is nearly 300 feet in depth, and ascended to the top of the south end of this Cretaceous ridge. The smooth top of this eminence rises to an elevation 5,900 feet above the sea, about 100 feet higher than the mesa to the east. On the west the surface drops down between 300 and 400 feet to a sag in the divide between Kennedy and Lees creeks, and beyond this sag the slope rises to the foot of Chief Mountain about 2½ miles away. At the point of the ridge facing Chief Mountain, in northeast quarter of section 26, township 37 north, range 15 west, fresh scarps have been produced by sliding on the underlying Cretaceous sandstone and shale. These show the capping of the ridge to be 100 feet or more of typical glacial till. This till is very stony, reddish below and gray above and very compact, probably partially cemented. The pebbles and boulders, a large part of which are finely facetted and striated, are mostly from the Altyn limestone, with subordinate amounts of greenish argillite and some red argillite. The till is notably fresh in appearance, but I attribute this fact to its having been so recently exposed.

I do not know the height attained by the ice of the last Kennedy Creek glacier. It may have spilled northward through the sags on either side of this ridge, but I doubt if the ridge was overtopped; certainly the

gravel mesa to the east stood at least 200 feet above the limit of the later ice. From its elevation and its isolated position it seems to me that the drift capping of this ridge is to be correlated with that on the mesa to the east as a remnant of the pre-Wisconsin glacial drift.

Deposits in the Vicinity of Belly River

Crossing the ridge between Chief Mountain and the main front of the mountain on the west, we descend the slope of Belly River Valley by the old Indian trail. At about 6,300 feet above sealevel we passed from the talus-covered slope of Cretaceous shale out along the crest of a scarp produced by landsliding. This exposure showed the flattened top of the ridge, between elevations 6,000 and 6,300 feet above the sea—that is, between 1,300 and 1,600 feet above Belly River—to be composed of glacial drift. On the following day Mr. Thomas made a more careful examination, and he described the deposit as glacial till and gravel, composed principally of limestone and quartzite from the Altyn formation, with subordinate amounts of red and green argillite, some Cretaceous sandstone, and a few clay ironstones. Much of the material is glaciated, the argillites showing striations most frequently. On a point nearer the mountain beside the new trail is an exposure of a similar deposit at about the same elevation.

Crossing to the west side of the valley, we climbed the heavily wooded slope. Between 5,750 and 5,950 feet above the sea, or between 1,000 and 1,200 feet above the valley bottom, we found a bare scarp face, the marginal slope of a shoulder standing out on the slope. The material exposed in this scarp is glacial till. All the pre-Cambrian formations are represented in the pebbles and boulders of this drift, limestones from the Altyn and Siyeh formations of the adjacent mountains, red and white quartzite, diorite, and amygdaloidal trap. Many of the argillite pebbles, especially, are well striated. Numerous blocks of tillite conglomerate were observed, but no ledges were seen projecting in place. Above the scarp the bench rises westward to the base of the cliff of pre-Cambrian rock, but with a slope much less steep than the general slope of the valley wall below. A similar bench, but somewhat less well marked, occurs to the north just across the ravine. No exposures were seen to show whether or not this bench is on a deposit of till. Seen from the east side of the bottom of the valley, the two appear to be parts of one bench, cut through by a broad sag, in the bottom of which is a sharp V-shaped ravine which drains two glacial cirques in the mountain slope above. This relation, taken together with the form of the bench and the char-

acter of the underlying deposit, suggests that the drift composing the bench was deposited under the same conditions as that capping the flat-topped ridges and mesas at a pre-Wisconsin stage of glaciation; that during the later extension of the Belly River glacier a tributary ice-stream, heading in the cirques above, cut through the bench, forming the broad sag, and that, after the melting of this glacier and that in the valley, post-glacial drainage cut the sharp notch.

Going northward along the slope to a point about one-half mile south of the international boundary, another similar bench is found at about the same elevation, with an exposure in the steep marginal slope, showing glacial till similar to that described above. The sides of the valley are heavily wooded and no detailed examination of them was made, so that I am not prepared to say what was the upper limit of the last glaciation, but I doubt very much if it overlapped these high-level deposits. These benches stand like remnants of high level terraces and appear to represent a former stage in the development of the valley.

Crossing the line into southern Alberta, high, straight-topped ridges like those described above were seen, one on either side of Belly River and one east of Lower Waterton Lake. Unfortunately, however, owing to a heavy fall of rain and snow, we were unable to examine the tops of these ridges. Seen with field glasses from the valley below, there appeared to be a heavy capping of coarse gravel on the ridges bordering Belly River, and since seeing the other high-level deposits I will be surprised if there are not on these ridges remnants of the same pre-Wisconsin glacial drift.

Age of the High-level Drift

Until further investigation of the relations of these deposits have been made no satisfactory conclusions can be drawn as to their full significance. As stated above, these flat-topped tracts have been regarded as remnants of a late Tertiary peneplain. If the widespread "quartzite gravels" capping these elevated tracts away from the mountains are to be correlated with this older glacial drift, then we may infer that the drift was deposited prior to the dissection of the Blackfoot peneplain, since the gravels must have been deposited prior to such dissection. The presence of glaciated pebbles in the deposit capping Milk River Ridge, the most typical remnant of this Blackfoot peneplain, and their presence also in the type exposure of the "Kennedy gravels" certainly point to such a correlation. If the valleys between these high-level tracts have been excavated to depths of 900 to 1,600 feet, and the headward exten-

sions of these valleys into the mountains have been correspondingly deepened since the deposition of this drift, we must refer a considerable part of the sculpturing of the mountains to Pleistocene time, for the contours marking the levels of the tops of this drift extend far up toward the heads of the mountain valleys, in most cases nearly or quite to the cliffs below the upper cirques.

Discussing the "Kennedy gravels," under the heading "Pleistocene (?)," Mr. Willis[11] wrote in part as follows:

"Gravels are widely spread on the highest tables of the plains north of Cutbank River and between the forks of Milk River. Their position suggests a correlation with the Kennedy formation. On the other hand, the gravels of the plains are composed chiefly of quartzite and presumably have lost the more soluble constituents, which still occur in the Kennedy formation. From this distinction greater antiquity may be argued for the high-level gravels of the plains.

"Salisbury in summarizing the results of Calhoun's investigations in 1901, in this region, says:[12]

"The high-level quartzite gravels on the plains east of the mountains are believed to be deposits made by streams at the close of the first epoch of baseleveling recorded in the present topography.

"If this belief be confirmed, the high-level gravels of the plains and the Kennedy formation are alike in genesis and derivation from the Lewis Range. They may, nevertheless, belong to widely different stages of uplift and erosion. The characteristics of the gravels and the physiographic record of the mountains may decide the relation on closer study."

Inasmuch as we have shown that both the gravels on Kennedy Ridge and those on a considerable part of Milk River Ridge contain glaciated material, the relation to the "quartzite gravels" farther east is probably somewhat different from what Mr. Willis had in mind, yet it is possible that they do belong to "widely different stages of uplift and erosion." A part of the "quartzite gravels" may be pre-glacial stream gravels, as believed by Calhoun, and much of the dissection of the Blackfoot peneplain and the correlated deepening of the mountain valleys may have been accomplished prior to the deposition of the high-level glacial drift. Mr. Campbell has suggested that instead of issuing from the mountains onto an undissected plain the earlier glaciers may have extended down valleys already cut in the plain, though to less depth than at present, and have spread laterally over the higher tracts on either side, leaving the thick drift largely as lateral moraines from which outwash deposits

[11] Op. cit., p. 329.

[12] R. D. Salisbury: Glacial work in the western mountains in 1901. Journal of Geology, vol. ix, November-December, 1901, p. 721. [Incorrectly cited by Mr. Willis as from January, 1902, number of this journal.]

spread, as over the broad plateau of Milk River Ridge. The thick deposits of drift adjacent to the valleys then acted as a protective capping, preventing the lowering of the thickly covered tracts while uncovered or less thickly covered adjacent tracts were further reduced. On this interpretation the high-level drift would still be referred to a pre-Wisconsin stage of glaciation, but the length of the succeeding interglacial interval would not be so great and less of the sculpturing of the mountains would be referred to Pleistocene time. Further investigations will be required to learn the full significance of this high-level drift, including its relation to the "quartzite gravels," which Dawson and McConnell found underlying the Keewatin drift in southern Alberta and Saskatchewan and grading westward into drift of the mountain glaciers, to which Doctor Dawson gave the name "Albertan" drift.[13]

Discussion

Mr. President: In answer to Doctor Atwood's question whether the pre-Wisconsin drift was deposited by valley glaciers rather than an ice-cap, I would say, in my opinion, it was deposited by valley glaciers, inasmuch as it is now found just east of the mountain front capping the ridges closely adjacent to the main valleys heading in the mountains. In these places the drift capping protected the soft Cretaceous rocks from erosion. Beyond, on either hand, where the drift may have been thin or absent the peneplain was reduced.

Answering the second question, the peneplain is pre-glacial. The drift was laid on the truncated edges of the upturned Cretaceous beds. The age of the drift is independent of the age of the peneplain excepting that it can not be so old as the plain. The important question is as to whether or not the dissection of the peneplain occurred prior or subsequent to the deposition of the drift. If subsequent to the deposition of the drift, then the drift is much older than that of the Wisconsin, and a considerable part of the sculpturing of the mountains must be referred to Pleistocene time, inasmuch as the contours marking elevations of these flat-topped ridges extend far up the valleys, in several instances to the foot of the cliffs below the cirques in the heart of the range.

The flat-topped mesas vary several hundred feet in maximum elevation, and it is not certain that all mark the same stage of deposition. More work is required before accurate differentiation can be made.

I have not had the opportunity yet to work out the relations of this old drift to the widespread quartzite gravels which have been regarded as

[13] Geo. M. Dawson and R. G. McConnell: "Glacial deposits of southwestern Alberta in the vicinity of the Rocky Mountains." Bull. Geol. Soc. America, vol. 7, 1895, pp. 31-66.

preglacial. A part at least of them may be outwash correlated with this old drift.

In regard to Professor Coleman's statement concerning the three drift sheets differentiated by Doctor Dawson, I am as yet uncertain as to the relations of this pre-Wisconsin drift to that described by Doctor Dawson. As I understood the statements in Doctor Dawson's papers, his old drift was traced up the valleys between the higher foothills, although scattered boulders were found on the latter. Here the old drift lies thick on top of the highest of the foothills.

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MINGLING OF PLEISTOCENE FORMATIONS[1]

BY B. SHIMEK

(*Presented before the Society December 29, 1911*)

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Introduction

Among the difficulties which beset the student of Pleistocene deposits in the field, none cause greater perplexity than the real or apparent intermingling of strata or masses belonging to different portions of this period. It thus sometimes appears as if masses of different drifts are transposed or interglacial formations are out of place.

Previous Work

Such intermingling has already been noted, particularly in connection with the Aftonian, at Afton Junction, and Thayer, Iowa, by Calvin,[2] and in western Iowa by Calvin[3] and the writer.[4]

[1] Manuscript received by the Secretary of the Society December 29, 1911.
[2] Proceedings of the Davenport Academy of Sciences, vol. x, 1905, pp. 18-30.
[3] Bull. Geol. Soc. America, vol. 20, 1909, pp. 137-139.
[4] Ibid., vol. 20, 1909, pp. 406-7; vol. 21, 1910, p. 133; Iowa Geological Survey, vol. xx, 1910, pp. 351-2, 355 and 371.

Recent Observations

ILLUSTRATIONS OF MINGLING

During the past year two striking illustrations of such mingling were observed by the writer, the one at Des Moines, Iowa, showing a transposition of yellow and gray loesses and a mixing of fossiliferous gray loess with Wisconsin drift, and the other at Sioux Falls, South Dakota, showing fossiliferous silt apparently between two drifts.

THE DES MOINES SECTION

Location.—This section was exposed for a short time in the excavation made for the heating plant of the East Des Moines High School. The locality lies near the border of the Des Moines lobe of the Wisconsin drift sheet, and loess is here frequently found under Wisconsin till.[5]

In a portion of the section under consideration, however, an unusual mingling of Pleistocene materials was observed during a visit made by the members of the staff of the Iowa Geological Survey, which was subsequently more closely investigated by the writer.

The loesses.—Throughout the region under consideration two loesses appear in many places. The lower is the usual bluish gray post-Kansan loess, which is here frequently fossiliferous, and the upper is the common yellow later loess.

The Wisconsin drift.—In the same region the Wisconsin till presents a common yellow phase, throughout which small boulders and pebbles are irregularly scattered. In the section under consideration a thickness of 10 to 15 feet is exposed.

Mingled loess and drift.—In the lower 6 to 8 feet of this section there appear gray bands and irregular streaks and masses which can not be distinguished from the gray post-Kansan fossiliferous loess, excepting for the presence of occasional pebbles, and, moreover, in a portion of the section a larger stratum of this gray material lies above yellow loess, thus producing an apparent transposition of the loesses.

A careful study of the section on the north and west sides of the excavation, however, revealed the cause of this unusual relation.

On the west side at the base the section (plate 41, figure 1) exposes about 5 feet of yellow loess with few fossils (*c*, figure 1). Above this is a stratum of gray loess 2 to 4 feet in thickness, with a few pebbles, and scattered shells of terrestrial mollusks for the most part broken. The remaining 10 to 12 feet of the section show Wisconsin drift, in the lower

[5] See also McGee and Call on the Löss and associated deposits of Des Moines. American Journal of Science, 3d ser., vol. xxiv, 1882, pp. 202-323.

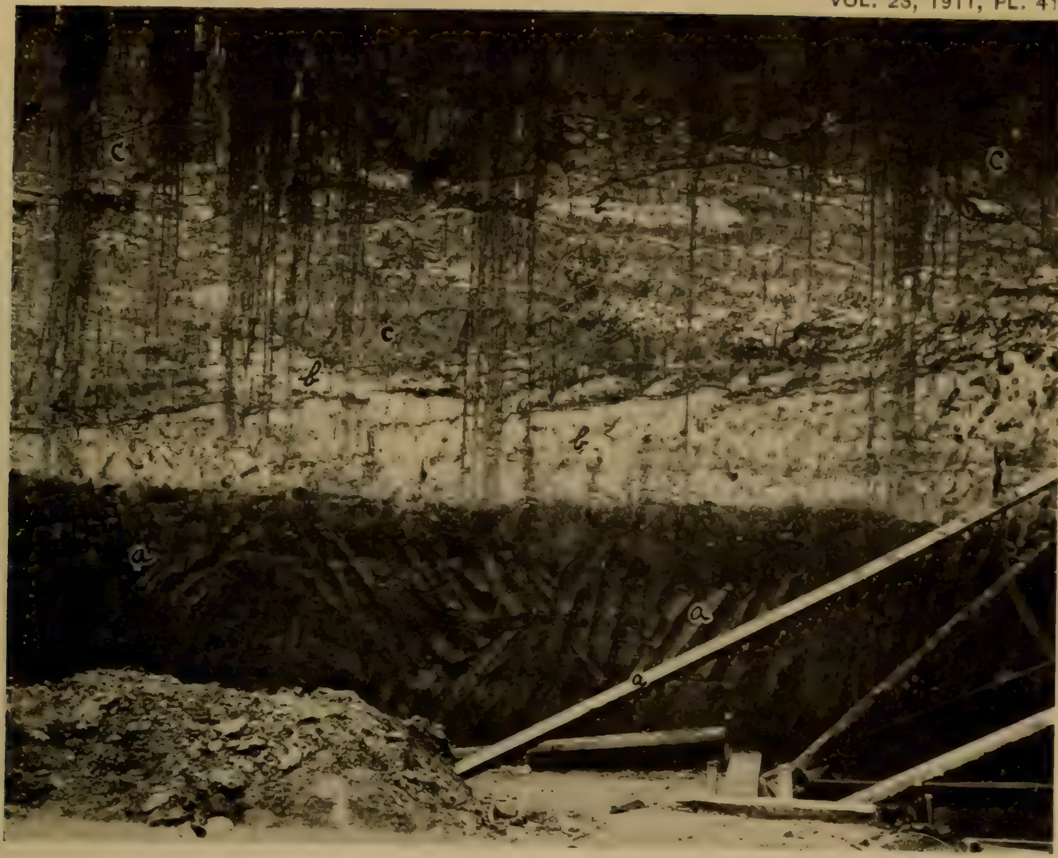

FIGURE 1.—SECTION AT EAST DES MOINES HIGH SCHOOL

a. Yellow loess; *b.* Gray loess mingled with Wisconsin pebbles; *c.* Wisconsin drift

FIGURE 2.—SECTION AT SIOUX FALLS

a. Gray silt with broken shells; *b.* Kansan drift

SECTIONS SHOWING MINGLING OF PLEISTOCENE FORMATIONS

half of which there are masses and layers of gray loess containing a few broken fossil land shells.

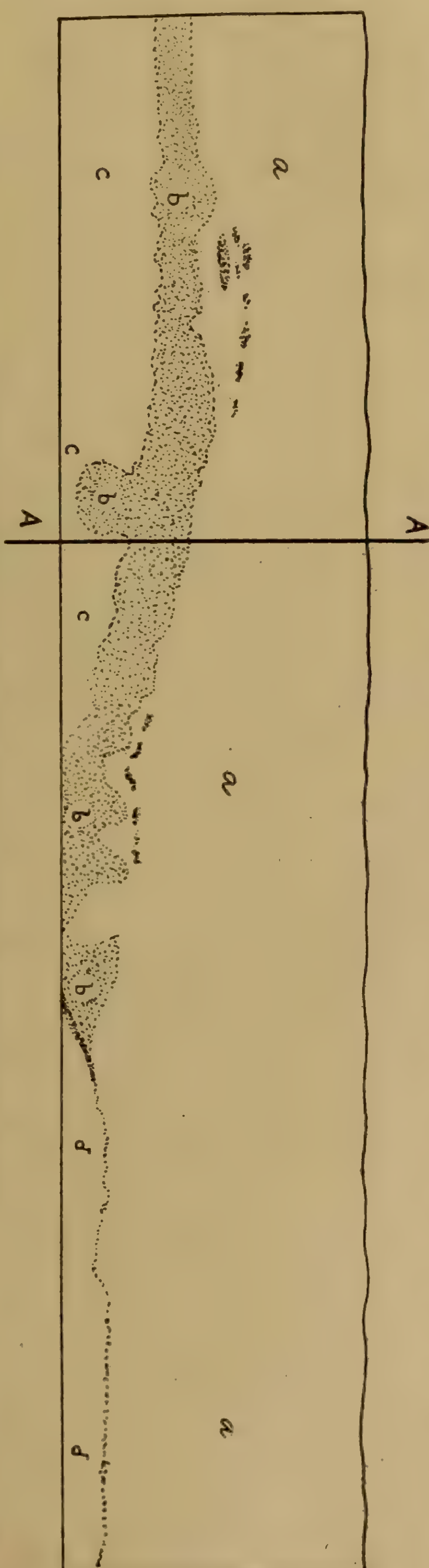

FIGURE 1.—*Section at Heating Plant of East Des Moines High School*

The line A-A represents the northwest corner of the excavation, the part to the right being the north side and that to the left the west side. The distance from A-A to *d-d* is about 50 feet. (*a*) Wisconsin drift, 10 to 12 feet thick, containing mixed masses of gray loess similar to (*b*), sometimes containing fragments of loess shells. (*b*) An irregular mixed stratum, 2 to 4 feet thick, consisting chiefly of gray loess, but more or less intermingled with Wisconsin drift, and containing loess fossils, derived evidently from (*d*). (*c*) Yellow loess, somewhat fossiliferous, younger than (*d*). (*d*) Gray, post-Kansan loess, undisturbed, containing entire loess shells. In (*b*) what is apparently a gray loess overlies the younger yellow loess (*c*), thus seemingly reversing the usual order, but its materials are older than (*c*).

On the north side the yellow loess soon disappears, as shown in figure 1 in the text, but the mixed gray layer, here distinctly folded, extends for about 50 feet to the east.

In this portion of the section the lower 6 to 8 feet of the Wisconsin also contains masses of fossiliferous gray loess.

To the eastward, on the north side, the section shows a distinct stratum of typical fossiliferous and apparently undisturbed gray loess, exposed for 50 feet to a depth of 2 to 3 feet.

A study of the entire section, as shown in text figure 1, suggests that the Wisconsin ice, moving in a southerly or southwesterly direction, somewhat as indicated by the arrow, pushed the mixed gray mass (*b*) from its position above (*d*) and deposited it above the yellow loess (*c*), which was also more or less disturbed, as indicated by a lateral excavation westward, which shows an irregular mass of yellow loess lodged above the mixed gray layer (*b*).

THE SIOUX FALLS SECTION

Location.—The Sioux Falls section here discussed

is located on the west side of Dakota avenue, north of West Third street, in Sioux Falls, South Dakota. It presents another example of interstratification which is of interest in this connection.

Briefly, the section shows a mass of gray silt lying between a lower stratum of Kansan drift, of which 7 to 8 feet are exposed, and an upper stratum of the same drift thickening northward to 10 or 12 feet.

The Kansas drift (plate 41, figure 2, *b*).—Both drift strata present the usual characteristics of the western Kansan. The heavy bluish joint clay is very calcareous and contains scattered pebbles and boulders.

The silt (plate 41, figure 2, *a*).—The silt is gray, calcareous, occasionally mingled with broken fresh-water mollusk shells of the pond types. The mass is exposed for about 75 feet, and distinctly dips downward toward the south. Its greatest thickness is 3 feet, and at the north it appears as if crowded or folded. Smaller masses of the same silt occur in the lower part of the upper drift stratum.

Another section, on McClellan street opposite Main avenue, shows the folding and crowding much better. Here a mass of silt, 20 feet long and 4 to 5 feet deep, imbedded in and completely surrounded by Kansan drift, shows, on its northern side, distinct evidence of pushing and folding.

The conclusion that these masses of fossiliferous silt are older than the Kansan, and that they were brought to their present position by the Kansan ice, is certainly warranted. The silt is evidently Aftonian.

Conclusion

If narrow vertical sections of the two exposures here discussed were made they would appear somewhat as follows:

The Des Moines section, west side:

Wisconsin drift, 10 to 12 feet (with bands of gray loess).
Gray, fossiliferous loess, 2 to 4 feet.
Yellow loess, 5 feet.

A normal section should show these loesses reversed and the larger section here shows how the reversal had taken place.

The Sioux Falls section:

Kansan drift, 10 to 12 feet.
Fossiliferous silt, 3 feet.
Kansan drift, 7 to 8 feet.

In this case it would be easy to jump to the conclusion that the silt is interglacial, separating two distinct drifts. The larger section shows that the Kansan is continuous and that the silt is intraglacial.

Manifestly, in both cases such sections would not show the true relation, and both show the need of great care in drawing conclusions from sections of limited lateral extent.

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TOYALANÉ AND LUCERO; THEIR STRUCTURE AND GENETIC RELATIONS TO OTHER PLATEAU PLAINS OF DESERTS[1]

BY CHARLES R. KEYES

(Presented by title December 30, 1911)

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DOMINANT FEATURES OF THE PLATEAU PLAIN

On the arid plains of the Southwest the two most striking features of the landscape are the lofty isolated desert ranges and the lower truncated hills which rise abruptly as walls above the general plains surface. The first mentioned of these relief characters has long attracted wide attention from travelers; the second, notwithstanding the fact that it is fully as impressive as the first, has scarcely received any notice at all. R. T. Hill alone seems to have given them special consideration and a name. For these plains above plains, or plains within plains, the term plateau plains appears to be a very appropriate title. At the present time particular interest attaches to the plateau plains because of the fact that they seem to furnish the most direct and convincing testimony we have of the deflative nature of general erosion under conditions of aridity.

In the dry regions plateau plains appear as even surfaces, more or less well elevated above the general plains surface about. As broad, truncated mounds they rise out of the vast expanse of level earth after the

[1] Manuscript received by the Secretary of the Society March 25, 1912.

manner of bold-coast isles out of a glassy sea. Mesas, or "tables," the Spanish-speaking people aptly denominate them. The margin of a mesa forms the brow of a precipitous escarpment, which is one of its most characteristic features. Not infrequently the upper part of the escarpment is a vertical wall 100, 200, or even 500 feet in height. Mesa de Maya (armored-mesa) and Llano Estacado (walled plain) are Spanish descriptive terms referring especially to this feature. The talus-like slopes below are steep, and their meeting with the general plains surface is sharp.

Profile and proportion are mainly functions of the geologic substructure. Some plateau plains are so small in area and so high that they stand boldly out of the general plain as conspicuous cones, or buttes. The Camaleon and Wagon Mound in eastern New Mexico are illustrations. Others, as the Enchanted Mesa and the Covero, in western New Mexico, and the Sunset Tanks buttes in Arizona, are only a few acres in areal extent. Toyalané and its neighbors are somewhat larger. From these to the great Chupadera Mesa and Mesa Jumanes, which are a dozen miles across and a score of miles in length, or the vast Mesa de Maya, which extends along the northern border of New Mexico a hundred miles, there is every size.

Structure of the Plateau Plain

The foundation of the plateau plain is generally some rock layer more indurated than the rest of the section. Structurally it may be made up of (1) remnants of former plains worn out on the beveled edges of folded strata, as in the cases of the Mesa Jumanes and the Chupadera Mesa; (2) slightly inclined strata of hard limestone or sandstone, which usually are intercalated in extensive beds of less resistant materials, as in the Chaca Mesa and other platform plains of the great Mesa Verde region; (3) almost horizontally disposed hard beds, from which the soft superposed layers have been stripped, as the Toyalané, El Moro, and the Tucumcari; (4) old lava-sheets, which cover soft shales and sandstones of which the Mesa de Maya, Mesa del Datil, and Acoma Mesa are conspicuous examples, and (5) surface-wash deposits, locally hardened through the evaporation of soil moisture, leaving the lime salts near the surface of the ground, well represented by the Galisteo Ceja south of Santa Fe.

Most flat-topped hills are now commonly ascribed to circumdenudation effects on an upraised peneplain. All remnants of the old graded surface are on the same general level. Throughout the arid region the plateau plains which rise above the surface of the general plains level also appear

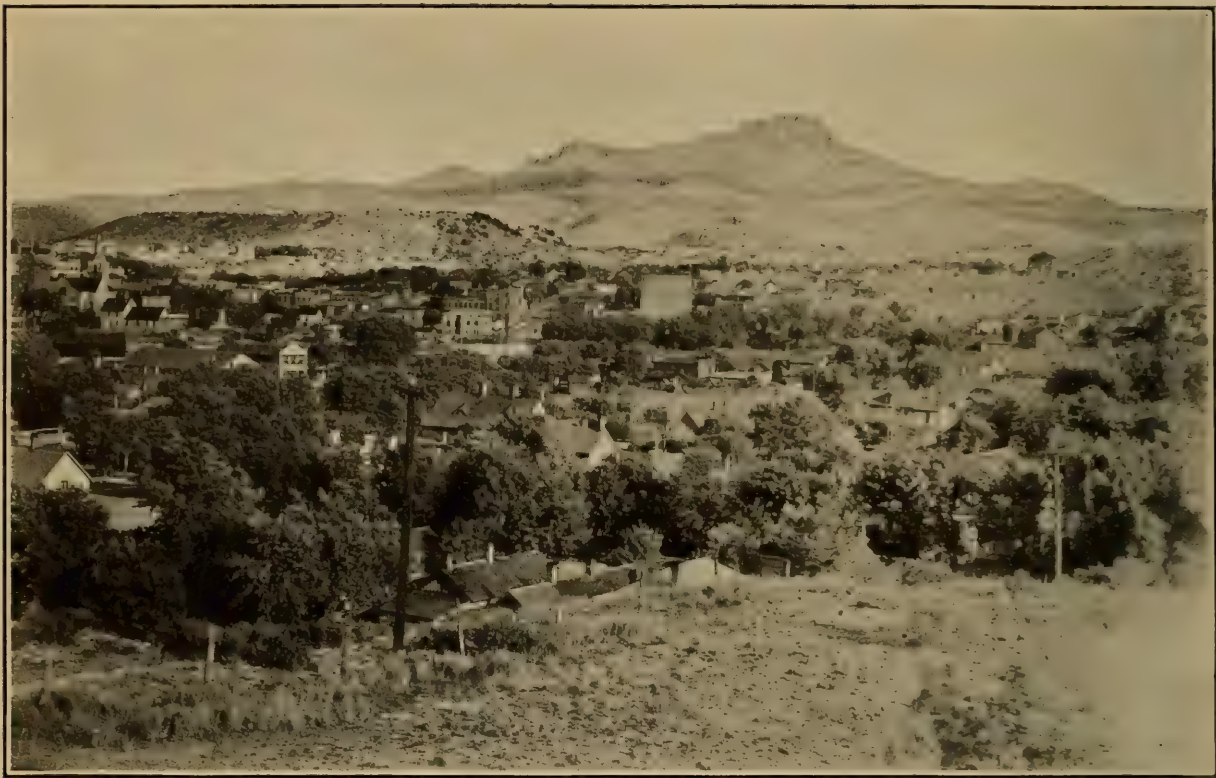

FIGURE 1.—FISHER PEAK, COLORADO
A spur of the Mesa de Maya, distant 15 miles and 3,500 feet above the basal plain

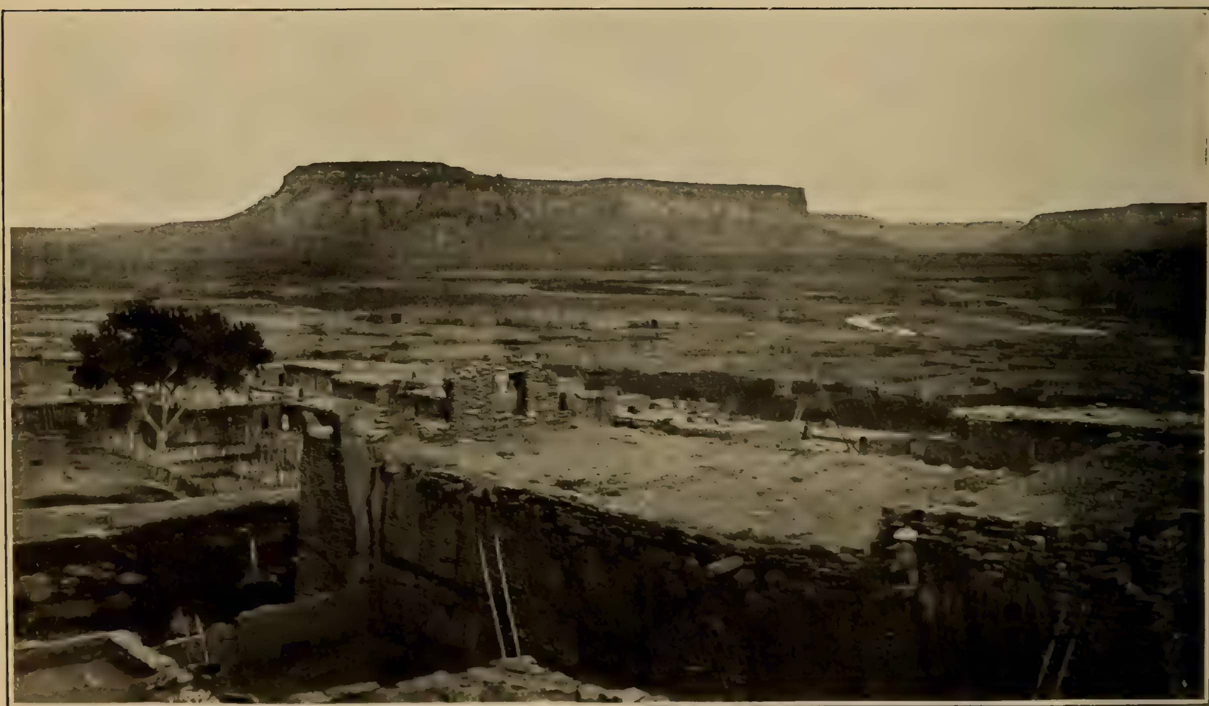

FIGURE 2.—TOYALANÉ, A TYPICAL PLATEAU PLAIN, NEAR ZUNI PUEBLO, NEW MEXICO

ILLUSTRATIONS OF PLATEAU PLAINS

to be the direct result of circumdenudation; but, as will be seen later on, of a somewhat different kind. In marked contrast to the humid-land effects the remnantal plains of the desert, whether their surfaces be on stratum planes, beveled tables of flexed strata, lava-sheets, or cemented regolith, are of quite different elevations, even in the same district. In New Mexico, for example, these plains attain all altitudes above the general plains surface, from a few feet in the instance of the very recently formed Malagro malpais, in the Hueco bolson, northeast of El Paso, to the broad Mesa de Maya, which is 3,500 feet above the general plains surface and 9,000 feet above sealevel (plate 42, figure 1). The Sierra del Datil, in western New Mexico, has a magnificent northward-facing escarpment 1,000 feet high, and in sight of it is the Acoma Mesa, 500 feet above the plains floor.

Toyalané

Toyalané is a conspicuous flat-topped mountain (plate 42, figure 2), situated in the Zuni Basin just over the continental divide in western New Mexico. The region is the largest, highest, and driest desert plain in this country. For the most part it lies 7,000 feet above tide level. Structurally and topographically it constitutes an essential section of the great Colorado dome, arching regularly from the Rio Grande to the Rio Colorado. Save in one place—the Zuni swell—its broad surface is unbroken by tectonic features. The region is preeminentlly one of plateau plains standing at all heights above the general plains surface. To the significance of this particular feature chief attention is here directed.

Around the southern slope of the dome there is, as Gilbert observes, one of the great lava tracts of the world, second in magnitude in our country only to the great northwestern lava field and fifteen times as large as the classical district of extinct volcanoes in central France. Sweeping in a broad crescent, 250 miles long, with Mount Taylor on one horn and the San Francisco Mountain on the other, the main body of lava flows, superposed in countless numbers, covers an area half the size of New York State. Beyond the borders of the crescent are numberless cinder cones, coulées, and limited lava-sheets, which spread out over the soft sedimentaries constituting the substructure of the plains in this part of New Mexico. In Arizona the hard Carboniferous limestone is the main surface rock, the shales once overlying it having been recently stripped off. Other volcanic evidences are the denuded necks and dikes. Lava-sheets form the foundation of many plateau plains.

Outside the limits of the lava fields the massive and more indurated

beds which are included between the thick sections of weaker strata take the place of the lava flows in the formation of the plateau plains.

Lava Flows of the Region

In the region under consideration extravasation of lavas has gone on at frequent intervals from the very beginning of Tertiary times almost, it may be said, to within the memory of men still living. The older trachytic and andesitic lava-sheets of the Mount Taylor district now stand 1,000 feet above the country around, and on this mesa rests the old volcanic cone itself, higher and more impressive than Vesuvius. To the north of Mount Taylor there are abundant evidences of still earlier volcanic activities, as shown in the forest of volcanic necks of that area, from which is swept almost every vestige of their cones and the plains on which they stood. Cabazon, a huge volcanic pipe, stands 1,200 feet above its base and is a landmark for 80 miles about.

Much younger, and 500 feet below the Mount Taylor plain, is Acoma mesa, 30 miles long and 15 miles wide, capped by basalt. At its foot, another 500 feet lower down, is a great basaltic flow, 50 miles long by 20 miles broad, covering the present plains surface. Even more recent are the coulées from the Tintero, on the Mesa Redonda, west of Mount Taylor, which finally enter the channel of the Rio San José at a point considerably below the level of the great flow just mentioned.

There are, then, four distinct periods of volcanic extravasation, between the first and last of which more than 1,000 feet of strata were removed from the entire region about. There are in the district many other lava-sheets at other heights; but between the four especially noted definite time relations are readily established.

On the continental divide the streams are their smallest. On a vast plain so situated drainage features are necessarily insignificant. Rainfall is the scantiest. These three conditions combined with arid climate give water action small opportunity to vigorously erode. On every hand the country clearly shows it. It is equally manifest that notable leveling and lowering has gone on at a rapid rate. Since the Mount Taylor and Datil plains levels were flooded with lava, general removal of surface rock has taken place to the extent of more than 1,000 feet, as already stated.

The extensive erosion is of a peculiar type. There is little of the sharp incision of the plains surface such as normally characterizes stream action, especially in a high-lying region having slopes of high gradients. Erosion is of the broad-basin type—wide, flat-bottomed, even plains between abruptly upturned rims against resistant rock-masses. As the lava

FIGURE 1.—LUCERO TYPE OF PLATEAU PLAIN
North rim of the Jornada del Muerto of Socorro County, New Mexico, distant 30 miles

FIGURE 2.—STRUCTURE OF ROCK-FLOOR IN THE GALISTEO BASIN NEAR LOS CERRILLOS, NEW MEXICO

LUCERO TYPE OF PLATEAU PLAIN AND ROCK-FLOOR STRUCTURE

flows and coulées became more and more numerous the separate basins became divided and smaller, but general lowering of surface went on without interruption. There can be no question but that the lava-capped mesas at varying heights represent former levels of the general plains surface.

The lavas manifestly flowed down the lowest lines of the plains, but as removal of the weaker beds on either side took place each flow was soon left as an elevation (plate 43, figure 1). A particularly instructive instance is shown near the Zuni pueblo, where an old valley is shown in section filled with basalt, being exposed in a mesa face several hundred feet above the present floor of the plain. Still more interesting is the coulée from the Sierra Lucero, at the northernmost extremity of the Mimbres range and 40 miles west of Magdalena. In this district the San Augustine plains are some 60 miles long and from 15 to 30 miles wide. A high rim completely surrounds them, giving them interior drainage. The substructure is mainly soft Cretaceous sandstones. From a midpoint on the south rim, not so very long ago, Lucero sent out a narrow coulée to the northward a distance of 15 miles, until it reached the opposite wall of the plains in the Sierra del Datil. Since that time the general surface of the plains has been lowered 50 to 100 feet or more. A small playa now occupies a part of the western division of these plains.

Most of the basin plains of this region have rock-floors (plate 43, figure 2). It would be impossible for these basins to be filled with the debris from the rims as has been ascribed to the Great Basin region.

To the north of the lava-capped mesas, mesa country still prevails, but the table tops are indurated layers, such as are seen in Toyalané and El Moro. When gently tilted, typical cuesta topography appears.

Eolic Character of the regional erosive Activities

That this high, dry, almost waterless waste on the continental divide should owe its landscape features chiefly to deflation seems to need little argument in this place. In the case of a district with alternating hard and soft strata, the Toyalané type of mesa might not always offer conclusive evidence in support of this contention. Against the lava flows of diverse ages as of the Lucero type no such objections can be raised.

These summit plains of the continent are a region of continual high wind and constant sand-storm. Nowhere else in the arid region of the Southwest is wind-scour in active operation so advantageously viewed. Nowhere else in this country are deflative effects and desert-leveling so well displayed. Nowhere else in all the world is general lowering of a

country by the winds so strikingly presented. Few places there are on this continent where stream action as a general erosional power is so manifestly utterly impotent.

In the existence of plateau plains in the desert at many different levels throughout the broad belts of the less resistant rocks there appears to be furnished one of the strongest proofs of the eolic character of the regional erosive activities, since in situations of this kind not only are rainfall and water action very deficient and wholly inadequate to produce the relief effects presented without the time element be vastly and unreasonably prolonged, but conditions are such in many cases as absolutely to preclude the intervention of stream work.

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VOL. 23, PP. 719-747 DECEMBER 17, 1912

ABSTRACTS OF PAPERS PRESENTED AT THE TWENTY-FOURTH ANNUAL MEETING OF THE SOCIETY, BUT NOT PUBLISHED IN FULL IN THE PRECEDING PAGES OF THIS VOLUME, TOGETHER WITH DISCUSSIONS OF PAPERS AS FAR AS PRESERVED.

E. O. HOVEY, *Secretary*

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NEW EVIDENCE ON THE TACONIC QUESTION

BY ARTHUR KEITH

(Abstract)

The reasons were given for reopening the old controversy and for selecting the north end of the Taconic Mountain as the crucial place. The principal views regarding the rocks of the Taconic Mountains were briefly outlined and

the geology of the region summed up. Five subdivisions of the Stockbridge limestone around the north end of the Taconics were described and attention was called to the extreme folding and metamorphism of the rocks. The slates of the mountains are sharply outlined from the Stockbridge limestone and the contact follows a rude semicircle around the end of the mountains. The characters of this plane of separation were discussed and the conclusion was reached that they could only be due to faulting. The bearing of this conclusion was briefly considered.

SOME FEATURES IN THE GRAND CANYON OF COLORADO RIVER

BY N. H. DARTON

(Abstract)

Several years ago the author measured sections at a number of points along the Grand Canyon to determine the stratigraphy of the Arizona Plateau. These sections were presented, and there was exhibited a colored preliminary geologic map of the Vishnu, Bright Angel, and Shinumo quadrangles similar to one now in the corridor of El Tovar Hotel at Grand Canyon.

PRE-CAMBRIAN FORMATIONS IN SOUTH-CENTRAL BRITISH COLUMBIA

BY REGINALD A. DALY

(Abstract)

A reconnaissance along the Canadian Pacific Railway line has established the following conclusions: 1. Dawson's "Nisconlith series" occurring in the Selkirk Mountains is not Cambrian, but represents the northern continuation of the "Beltian" (Belt terrane) rocks at the International Boundary. 2. Dawson's "Nisconlith series" of the Shuswap Lakes area (west of the Selkirks) is an entirely different pre-Cambrian and pre-Beltian group of sediments, which unconformably underlie the "Nisconlith series" of the Selkirk section. 3. The Adams Lake volcanic series conformably overlies the thick limestones of the "Nisconlith series" in the Shuswap Lakes area and is of pre-Beltian age. 4. The "Shuswap series" of the Shuswap Lakes is not a distinct gneissic group unconformably underlying the "Nisconlith series," but is the facies of the "Nisconlith series" produced where that series was thermally metamorphosed by batholiths. 5. Though these pre-Cambrian rocks are typical crystalline schists, their metamorphism of the regional type was not due to dynamic action; it was "static" metamorphism (Belastungsmetamorphismus of Milch). 6. The pre-Cambrian rocks are much less deformed (upturned) than the overlying Carboniferous or Triassic rocks, illustrating the small depth of the earth-shell which underwent strong folding in post-Cambrian time. 7. The petrography of this pre-Cambrian and pre-Beltian terrane strongly suggests that it furnished the greater part of the elastic material of the Rocky Mountain geosynclinal prism. (Beltian and Cambrian sediments.)

COVEY HILL REVISITED

BY J. W. SPENCER

Published as pages 471-476 of this volume.

Discussion

Prof. J. B. Woodworth stated in brief that the pool and accumulation of blocks in "the Gulf" at Covey had been interpreted by Gilbert, himself, and others as evidence of a torrential flow of waters out of all proportion to the existing stream. As for the altitude of the upper marine limit on the north side of Covey Hill, he had revisited the field since the paper, "On the ancient water-levels of the Hudson-Champlain Valleys," was published, in company with Professor Fairchild, and accepted the latter's determination of the upper marine limit. The elevations given in that report were based on an old and inaccurate altitude of Covey Hill, and can not be relied upon.

Prof. H. L. Fairchild: Dr. Spencer's present views are a great change from those of the last twenty years, during which he has advocated the marine origin of all the glacial lake beaches, including the Iroquois. Now he doubts the marine origin of the lowest series of close-set bars in the Champlain-Saint Lawrence depression, and which clearly correlate with deposits containing marine fossils, and which have for nearly a century been recognized by all workers as oceanic. There can be no doubt of the marine origin of the Covey Hill beaches. The deformation of the Iroquois plane clearly proves that the Covey Hill bars were below sealevel at the close of the Iroquois time. The absence of a great cataract cliff at the Covey Gulf is due to the fact that the ice-sheet lay close against the west slope of the Champlain Valley or the east slope of the Covey Hill promontory, and the outflow of Iroquois waters at the gulf was held up at high level and produced the extensive areas of bare rocks on the Mooers quadrangle, formerly described by Professor Woodworth. The history of this locality will be given and the features described in my paper, "Closing phase of glaciation in New York," to be delivered later in this meeting.

Dr. Spencer replied: Points emphasized in my paper are: That Covey Hill Gulf is due to postglacial local erosion and not to drainage of a glacial lake; that the spillway over the hill was from a glacial lake other than the Iroquois, probably an older one; that I saw no evidence then of any of the beaches being marine. In making the original surveys of lakes Warren, Algonquin, and Iroquois, I had adopted the hypothesis that they were not of glacial origin. At that time the phenomena of the spillways had not been well investigated. Since my return to these researches I have accepted glacial dams on fuller evidence. For this change of hypothesis, or progress, my friend, Professor Fairchild, would impale me. But my former argument in favor of the marine origin of Lake Iroquois he has adopted in support of Gilbert Gulf, of whose existence I have failed to find evidence.

GEOLOGY OF STEEP ROCK LAKE

BY ANDREW C. LAWSON

(*Abstract*)

The paper gave a brief historical summary of the geology of Steep Rock Lake and an account of a visit to the lake during the summer of 1911. The observations that were made confirm the conclusion of Smyth as to the existence of the Steep Rock series as a distinct member of the Archean and its

unconformable relation to a granite gneiss of the basement complex. The conclusion is that the Steep Rock series was unconformably deposited upon the Keewatin. The probable position of the Steep Rock series in the geological scale is given as beneath the Animikie, with a series of quartzites and slates, which is called the Seine series, between the Animikie and the Steep Rock series. The discovery was announced that the limestone which was estimated by Smyth to be not less than 500 or more than 700 feet in thickness is fossiliferous.

FOSSILS OF LOWER LIMESTONE OF STEEP ROCK SERIES

BY CHARLES D. WALCOTT

(*Abstract*)

Notes on a description of a new genus and two species of sponges found by Dr. Andrew C. Lawson in the limestone of the Steep Rock series.

Discussion

Prof. A. P. Coleman: It is extremely interesting to hear of the discovery of distinct fossils in the Steep Rock series, which other geologists as well as myself have believed to be Huronian. The limestones are very fresh looking, but hitherto no well-defined fossils have been found in them. There are, however, carbonaceous beds in the Huronian which have been thought to imply life, even though fossils were not known.

ORIGIN OF THE SEDIMENTS AND COLORING MATTER OF THE EASTERN OKLAHOMA RED BEDS

BY J. W. BEEDE

(*Abstract*)

Recent investigations seem to show that the sediments of the lower red beds of Oklahoma were derived from the Arbuckle-Wichita Permian land-mass. The conclusion is based on the amount of material removed and the geographic distribution of sediments bordering the mountains.

Coarse limestone conglomerates of great thickness and conglomerates of crystalline rocks, both possibly of subaerial origin, dovetail into red beds. Belts of sandstone have been found extending into the area of finer sediments farther away from the mountains, apparently indicating the location of stream debouchures at the margin of the shoal sea. The extreme shallowness of the water is clearly indicated in the structure of the beds.

The coloring matter is thought to have been derived from the solution of the 7,000 or 10,000 feet of pre-Carboniferous limestone which formerly covered the Arbuckle-Wichita Mountains and much of the surrounding region. The solution of the limestone furnished optimum conditions for the oxidation of its iron content, as it does at the present time in the limestone regions of the Mississippi Valley, southern Europe, West Indies, and elsewhere. Moreover, the solution of the pre-Carboniferous limestones and the conglomerates of the Arbuckle-Wichita region now in progress produces a red residuum

practically indistinguishable from red beds sediments. The red granites, red porphyries, and other crystalline rocks of the region under discussion contributed their share of material to the red beds. Other factors may have entered largely into the formation of the red beds of western Oklahoma.

Discussion

Dr. I. C. White: In the Monongahela series of West Virginia we get the same kind of transition from fresh-water limestones to red shales in passing from the northern portion of the State southwestward toward the Great Kanawha River. There are no red beds whatever in the Monongahela series at the northern line of West Virginia, but as the limestones disappear southwestward red shales make their appearance, along with much more sandy material in the shape of gray and brown sandstones.

MESOZOIC STRATIGRAPHY OF ALASKA

BY G. C. MARTIN

(*Abstract*)

Mesozoic strata cover vast areas in Alaska and constitute a large proportion of the thickness of the local stratigraphic column. The recent work of the U. S. Geological Survey has resulted in the accumulation of a great amount of stratigraphic information which is chiefly either unpublished or scattered through reports on local districts or on mineral resources.

This information is of importance not only because it constitutes so large a proportion of the local geologic facts, but because there are obvious relationships in the Alaskan sections which contribute to a better understanding of horizons in other parts of North America.

An attempt is made in this paper to summarize all existing information; to correlate the recognized horizons, not only between different parts of the territory, but with the standard sections in other parts of the world, and to present a proposed local classification of the Mesozoic rocks.

Triassic rocks are widely distributed in Alaska, and include over 5,000 feet of marine sediments containing invertebrate faunas which permit of correlation with several well-recognized horizons of the western part of the United States and of Europe. Probably an equal thickness of volcanic rocks is present.

The Jurassic is well developed throughout much of southern Alaska, and is also present in the Arctic region. The Jurassic rocks are richly fossiliferous, both marine invertebrate and plants being present. These faunas and floras, although still largely undescribed, permit of correlation with the standard European sections. Lower, Middle, and Upper Jurassic horizons are recognized, the aggregate thickness of the fossiliferous Jurassic rocks exceeding 10,000 feet.

Both Lower and Upper Cretaceous rocks have been recognized in all of the larger geographic subdivisions of the territory, the aggregate thickness of the beds being many thousand feet. The Lower Cretaceous rocks are chiefly marine and contain faunas allied to those of Russia. The Upper Cretaceous rocks include fossiliferous marine sediments in which the Indo-Pacific fauna

has been recognized and coal-bearing deposits of terrestrial origin. The latter possibly include beds transitional into the Tertiary.

DARK SCALE OF HARDNESS

BY ALFRED C. LANE

(Abstract)

The hardness of a mineral is its resistance to shearing stress. Like other properties of minerals, it may differ in different directions. When two similar surfaces are rubbed together, the softer mineral leaves a powder (streak) on the other. In order to be sure which mineral gives the streak, it is at times convenient to have besides the common Mohs scale of hardness, composed of light minerals, a "dark scale of hardness" of minerals whose color and streak are dark, especially in teaching. For such minerals the following properties are desirable: quickly recognizable, easily obtainable, hardness uniform.

The following minerals have been used by the writer: (1) Graphite, with one good cleavage, at one extreme in the white scale; at the other extreme in the black. (2) Stibnite (Sb_2S_3), with two good cleavages, bladed. (3) Galenite (PbS_3), with three good cleavages. (4) Iron (use soft wire nail), magnetic, ductile. (5) Niccolite (NiAs), characteristic color, no cleavage. (6) Magnetite (Fe_3O_4), magnetic, brittle.

The minerals mentioned seem fairly satisfactory. Above 6 the author does not know whether spinel or some other mineral would be more desirable, but as there are comparatively few minerals concerned, it is not important.

DEMONSTRATION OF RELATIVE REFRACTION

BY ALFRED C. LANE

(Abstract)

The method of determining relative index of refraction developed by Exner, Becker, and Schroeder van der Kolk[1] may be demonstrated to a class as follows: A large beaker of water placed just a little to one side of a window or other source of light will show a bright streak on the farther side, having a higher index than the surrounding medium. A test tube full of air placed in the beaker will show a bright streak of total reflection on the nearer side, the air within having a less index than the surrounding medium.

STRATIGRAPHIC STUDY OF THE APPALACHIAN AND CENTRAL STATES WITH REFERENCE TO THE OCCURRENCE OF OIL AND GAS

BY GEO. H. ASHLEY

(Abstract)

It had always been supposed by the oil and gas men that the Appalachian region, extending from Pennsylvania to Alabama, was a stratigraphic unit, and it has been a mystery that eastern Kentucky, Tennessee, and Alabama should not yield as much oil and gas as Pennsylvania or West Virginia. The

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[1] Report Michigan Geological Survey, vol. vi, p. 154.

mystery largely disappears when a comparative study is made of the stratigraphy of the Appalachians as a whole. The paper compares graphically the stratigraphy of the southern and northern Appalachians and the Central States with reference to the occurrence of oil and gas.

GRANULARITY LIMITS IN PETROGRAPHIC-MICROSCOPIC WORK

BY FRED E. WRIGHT

(Abstract)

In this paper the petrographic microscope is treated as a measuring device for the exact determination of the optical properties of crystal plates, especially of minute crystal fragments and of crystallites. The methods now available for the purpose are considered briefly with special reference to their accuracy and applicability to the investigation of fine-grained silicate preparations. Attention is directed in particular to the lower granularity limits at which satisfactory measurements of the different optical properties of a mineral grain can still be made.

ARKANSAS DIAMOND-BEARING PERIDOTITE AREA

BY L. C. GLENN

(Abstract)

Evidence was offered of the circulation of presumably thermal waters about the margin of the original pipe described by Branner. A supposed extension of the peridotite area proves to consist of disintegrated peridotite mixed intimately with well-rounded quartz sand and occasional water-worn chert pebbles and was evidently water-laid. Indications of the age of this material narrow down the period within which the extrusion of the peridotite must have occurred.

Discussion

Prof. A. H. Purdue: The paper by Professor Glenn is of great interest to me, for it appears to establish the age of the peridotites as post-Lower Cretaceous and pre-Upper Cretaceous, for recent work over the area by Mr. H. D. Miser and myself had disclosed a marked unconformity in the immediate locality of the peridotite, between the Lower and Upper Cretaceous. The material of the intermediate area described by Professor Glenn was in all probability put down while the Upper Cretaceous shoreline occupied this area, the material, of course, having been derived from the disintegration of the peridotite.

VARIATION OF THE OPTIC ANGLE OF GYPSUM WITH TEMPERATURE

BY EDWARD H. KRAUS

(Abstract)

By using an oil bath to determine the variation of the angle of the optic axes of gypsum at different temperatures, it is found that gypsum is optically uniaxial at approximately 90 degrees Centigrade for sodium light. Although

Mitscherlich observed in 1826 that this change takes place at about 92 degrees, the values given later by Des Cloizeaux, and more recently by Tutton, both of whom used air baths, are from 15 to 26 degrees too high. Nevertheless, Des Cloizeaux's value of 116 degrees Centigrade for red light is the one commonly quoted. By plotting the values of the apparent angles of the optic axes at various temperatures up to 132.5 degrees Centigrade, it is easily seen that the angle changes most rapidly in the vicinity of the uniaxial point, that is, between 80 and 100 degrees, and, further, that one axis, as was pointed out by Naumann, changes its position more rapidly than the other.

PARAGENESIS OF THE ZEOLITES

BY J. VOLNEY LEWIS

(*Abstract*)

Zeolites and other secondary minerals occur in the Newark igneous rocks of New Jersey. (1) In cavernous spaces in the ropy pahoehoe of the extrusive Watchung basalts; (2) in fault fissures and fault-breccia of both the basalts and the great intrusive sill (Palisades, Rocky Hill, and Sourland Mountain); (3) less commonly in the ordinary joint cracks of both the extrusive and the intrusive types. The rocks are essentially the same in both chemical and mineral composition, consisting essentially of pyroxene and plagioclase feldspars, with quartz-bearing and olivine-bearing facies. The zeolites and related silicates are essentially combinations of the feldspathic elements and water, with the addition of fluorine in apophyllite and boron in datolite; the accompanying amphibole, biotite, chlorite, epidote, serpentine, and talc are derivatives of the pyroxenes. Hypotheses of origin dependent on the action of meteoric waters are inapplicable on account of difficulties of circulation, deoxygenation, and sources of fluorine and boron; on the other hand, contact metamorphism by the intrusives has produced in the adjacent shales minerals into which fluorine and boron enter, presumably by emanation from the magma. Hence magmatic waters are regarded as the most probable agent in the formation of the zeolites and accompanying minerals.

Discussion

Prof. A. C. Lane: My experience would rank epidote somewhat higher. Can we not conceive meteoric water working down, growing hotter, dissolving silica, and becoming deoxidized by the reducing action of the basaltic glass containing silica chlorides and hydrocarbons suggested by Brun, and thus being in condition to deposit zeolites?

Prof. F. R. Van Horn: Professor Lewis spoke of apatite as evidence of deep-seated waters being the cause of foundation of zeolites. I would like to ask if he has been able to distinguish apatite of two origins—one by magmatic differentiation and another which is associated directly with zeolite minerals.

Dr. Lewis replied: Apatite has been observed as a rock constituent, but not seen in the vein minerals. It is possible to conceive of meteoric waters penetrating the rock, becoming hotter with depth, and becoming charged with the volatile magmatic emanations to such an extent that they would be practically indistinguishable from magmatic waters.

OCCURRENCE OF PETROLEUM ASSOCIATED WITH FAULTS AND DIKES

BY FREDERICK G. CLAPP

(*Abstract*)

Several instances of the occurrence of petroleum along faults and dikes were described geologically and with reference to their place in the classification of oil and gas accumulations.

COLOR SCHEME FOR CRYSTAL MODELS

BY GEORGE HALCOTT CHADWICK

(*Abstract*)

The proposed scheme of coloring uses the primary colors for the different axes and applies to the various faces colors determined by the axis or axes which the face parallels, with such modifications as are necessary, especially in the isometric forms. The way in which this plan works out for the pyramids and prisms of the tetragonal and hexagonal systems suggests a query as to whether the ordinarily accepted usage of the terms "first order" and "second order" in the hexagonal system is not exactly the opposite of their application in the tetragonal and possibly in need of rectification.

NEW MINERALS FROM THE FAVAS OF BRAZIL

BY OLIVER CUMMINGS FARRINGTON

(*Abstract*)

Study of the Favas accompanying the diamonds of Brazil (analyses by H. W. Nichols) shows the presence of two new minerals. One, geraesite, is a hydrous barium aluminum phosphate more acidic than gorceixite; the other, minasite, is a hydrous aluminum oxide, which fills a gap in the series of hydrous aluminum oxides and shows important parallelisms between the hydrous oxides of iron and aluminum.

RESINS IN PALEOZOIC COALS

BY DAVID WHITE

(*Abstract*)

Resins are present in most coals, except possibly those of the highest grades, the amount depending in general on the degree of concentration (residual) resulting from the decay and reduction of the attending plant structures. Interesting examples of megascopic resins in coals from the Carboniferous of the Mississippi Valley and Montana indicate the presence of resin in the Paleozoic coals in proportions probably as large as in the coals of the Mesozoic and Tertiary.

ONYX DEPOSITS IN EAST TENNESSEE

BY C. H. GORDON

(Abstract)

The existence of onyx deposits in east Tennessee has been known for a long time, and attempts have been made at recurrent intervals to utilize the material. Thus far no success has attended these efforts, but with persistent frequency hopes are aroused over some new "find" and glowing announcements are made of the possibilities of this industry. The onyx found is of cave formation and for the most part represents the remnants of vanished caves. The character and extent of the deposits and the possibilities of their commercial development were discussed.

SUGGESTION FOR MINERAL NOMENCLATURE

BY HENRY S. WASHINGTON

(Abstract)

The science of mineralogy is a branch of descriptive chemistry, but in its classification differs from it in that the crystal form is as necessary as the chemical composition for the definition of a mineral. The nomenclature is far behind the classification, and by its general use of a single termination and arbitrary name roots gives no idea of the characters or relationships of minerals. It is suggested that minerals be regarded as salts of mineral acids, the salts being characterized by certain crystal forms, as was first suggested by Penfield in discussing tourmaline and amphibole. The proposed names will be formed in analogy with those of inorganic salts, the basic portion being denoted by the chemical names of the base or bases, and the acidic (negative) by adjectives ending in *-ate* for salts of sulpho- and oxy-acids, and in *-ide* for binary compounds (sulphides, oxides), the root of this portion being derived from the present name of some well known member of the group, and the root implying always a definite crystal system and adherence to a given type of chemical composition.

GLACIAL DEPOSITS OF THE CONTINENTAL TYPE IN ALASKA

BY R. S. TARR AND LAWRENCE MARTIN

(Abstract)

The glaciation of the interior of Alaska forms a striking contrast with the coast, where glacial erosion forms predominate, the deposits being largely under water, except for (1) 1,600 square miles east of Yakutat Bay, (2) 16,000 square miles in the Cook Inlet-Susitna Valley region, and smaller areas. The interior, between the Coast ranges and the Endicott-Rocky Mountain system, where the National Geographic Society's party made some studies in 1911, has extensive glacial deposits of the continental type, previously described in part by Russell, Brooks, and others, and similar to those of United States. These include at least (*a*) 15,000 square miles in the Copper River basin, (*b*) 27,000 square miles in the Tanana and Kuskokwim valleys,

(*c*) 17,000 square miles in the Yukon flats, (*d*) several thousand square miles on the upper Yukon region in Canada and smaller areas. The dominant material is outwash, and this extends long distances outside the country actually glaciated. In places there is wind-blown loess associated with this. In some localities it is still being deposited, and in the Copper River basin it has been accumulating during the time required for the growth of six or seven generations of trees. There is also some till, but this is largely buried beneath outwash. Lake deposits, eskers, kames, and buried vegetation are also found, but thus far no one has found drumlins. In thickness some of these deposits rival those of the Middle West, one instance being known of probably 800 feet of gravel, sand, etcetera, grading out from the mountains to less than 100 feet fifty miles away. The presence or absence of these drift deposits seems to be chiefly a matter of favorable topography and existing deglaciation—a process much like that formerly in progress in northeastern and central United States.

Discussion

Dr. C. A. Davis: The estimate of the age of the deposits shown in the photographs, based on the age of the included stumps alone, is very conservative, since the stumps shown are thoroughly decayed. Such decay is usually subaerial, and when once the stump is buried it practically ceases. If the average age of the stumps shown in the strata were 150 years, 50 years would probably be a fair estimate of the added time required to bury it completely, so that at least 200 years is represented in each layer of stumps.

Prof. W. M. Davis called attention to the large volume of peripheral deposits as indicating large erosion in mountain sources of glaciers; still larger when it is recognized that much glacially eroded material is not recognizable in glacial deposits, but is washed far down the outflowing rivers and even to the sea.

PRE-WISCONSIN GLACIAL DRIFT IN THE REGION OF GLACIER PARK, MONTANA

BY WILLIAM C. ALDEN

Published as pages 687-708 of this volume.

Discussion

Prof. A. P. Coleman: At Calgary, 100 miles north of the region spoken of by Mr. Alden, there are two or three sheets of boulder clay. One coming from the mountains is lowest and is covered by interglacial material, followed by a boulder clay containing Laurentian boulders which came from the Keewatin center. The lowest boulder clay must be much older than the Wisconsin ice age.

Prof. W. W. Atwood: Mr. Alden has been working in a region of unusual interest from the standpoint of glacial geology. It is probable that he will secure some other significant data. I should like to ask a few questions.

Is it not possible that the Blackfoot peneplain, as described by Mr. Willis,

exists in the area east of the mountains, but farther from the base of the range than Mr. Alden has yet worked?

May not the Blackfoot peneplain pass under the older glacial drift, as described by Mr. Alden?

Are the older glacial deposits described in this paper on the highest mesas bordering the range, or are there still higher levels where there may be gravel deposits, sometimes referred to as "high-level gravels?"

Are the older glacial deposits associated with the modern canyon in such a way as to indicate that the ice which left them moved down these troughs?

SOME GLACIAL DEPOSITS EAST OF CODY, WYOMING, AND THEIR RELATION TO THE PLEISTOCENE EROSIONAL HISTORY OF THE ROCKY MOUNTAIN REGION

BY WM. J. SINCLAIR

(*Abstract*)

Twelve miles east of Cody, Wyoming, in the Eocene Bad Lands in the vicinity of McCulloch Peak, angular blocks of Paleozoic limestone occur at elevations of 6,000 feet above sea, either on the crests of narrow ridges separating deep valleys cut in the Bad Land clays or on terraces several hundred feet above the Shoshone River. No other rocks than limestone have been seen in these high-level deposits, but at lower levels abundant pebbles and boulders of andesite may be found, all of which are water-worn, while the high-level material is highly angular, the only sign of abrasion being the pitted surface produced by the solvent action of rain water. Corals and bryozoa frequently appear in relief on the rain-etched surfaces. Individual fragments vary in size from a few inches or less to blocks 6 by 8 by 4 or 5 feet. The source of the limestone is, undoubtedly, the Paleozoic formations of the mountains to the west of Cody. Glacial ice is the only known agent capable of transporting blocks of the size indicated. If they have been transported by ice, 1,200 feet or more of canyon cutting has intervened since their deposition, for they are stranded on narrow divides and comb ridges at least that high above the Shoshone River. If they are to be correlated with the first glacial advance in the Rocky Mountain region, much of the deep dissection of such intermontane troughs as the Bighorn Basin must be regarded as an event of Pleistocene time.

Prof. W. W. Atwood: It appears from Mr. Sinclair's presentation that he has secured some very important evidence on the recent physiographic history of the Rocky Mountains of Wyoming. I should like to ask him two questions: How far away from the range are the large boulders which he attributes to glacial origin? Are the deposits which he describes opposite the present canyon in the mountains to the west?

Dr. Sinclair, in reply to the foregoing and to questions put by Prof. W. M. Davis, said: The limestone boulders are twelve miles east of Cody, opposite the mouth of Shoshone Canyon. I doubt if boulders were transported down a hypothetical slope as sketched by the President on the black-board, but they seem to have been carried across the Eocene filling of the basin to the east of the mountains previous to the dissection of the basin deposits.

EVIDENCE OF THREE DISTINCT GLACIAL EPOCHS IN THE SAN JUAN MOUNTAINS OF COLORADO

BY WALLACE W. ATWOOD AND KIRTLEY F. MATHER

(*Abstract*)

Abundant evidence of two distinct Glacial epochs has been reported by several investigators from various mountain ranges in the western portion of the continent. During the past season glacial deposits have been examined and mapped about the margin of the San Juan Mountains, which deposits have been interpreted to indicate an epoch of glaciation distinct from the two later epochs that have been clearly recognized in the history of the range.

For convenience, the three distinct epochs are referred to, beginning with the oldest, as "San Juan," "Big Horn," and "Uinta."

The composition, distribution, and topographic relations of the San Juan glacial drift indicate that this earliest known epoch was separated from the Big Horn Glacial epoch by a much longer time than the Big Horn was separated from the Uinta. The two later epochs appear to have been separated by a much longer time than has elapsed since the last disappearance of glacial ice from the range. The San Juan Glacial epoch is so far removed from the present time that the glacial deposits of that epoch are found at but a few places, where conditions were most favorable for their preservation.

There are reasons for believing that the San Juan Glacial epoch may have been characterized by small ice-caps among the western ranges rather than by Alpine glaciers, which were the prevailing type during the Big Horn and Uinta epochs.

There are good reasons for believing that the San Juan epoch preceded the development of the great canyons among the mountains, and therefore that much of the sculpturing which has given form to the scenic features of the range is inter- and post-Glacial in origin. The time relation of the epochs of glaciation to other events in the physiographic history of the range was discussed.

GLACIAL INVESTIGATIONS IN MINNESOTA IN 1911

BY FRANK LEVERETT

(*Abstract*)

A sheet of old calcareous drift deposited by an ice-sheet radiating from central Canada covers nearly all of Minnesota and extends into western Wisconsin. The prominent moraines of western Minnesota, named by Upham Itasca, Leaf Hills, and Fergus Falls, were formed in the order named, as is shown by the glacial drainage from them. The rock constituents of these moraines show remarkable disintegration that suggests a possible pre-Wisconsin age. After these moraines were formed by the ice radiating from central Canada, there followed an ice-movement radiating from the high tableland northeast of Rainy Lake. This moved across the northern ends of the above-named moraines and extended a few miles beyond the portion of the Mississippi above Saint Paul. This produced the so-called "red drift." After this ice-movement waned, there followed a re-advance of the ice-sheet radiating from central Canada which had its main axial movement through the Red-Minnesota-Des

Moines Valley, but which also extended southeastward across the portion of the Mesabi Range west from Hibbing, Minnesota, and spread to the left and right in a basin which divides its drainage between the Saint Louis and Mississippi Rivers. This ice-movement deposited the so-called "gray drift" of the Minnesota Reports. It forms only a thin veneer on the portions of the Leaf Hills and Fergus Falls moraines which it overrode, and it failed to cover all of the Leaf Hills moraine. The correlative position of the Lake Superior Lobe is found to have been but little beyond the western end of the present lake, in Carleton County, Minnesota. A large glacial drainage line opened a great valley along the Saint Louis between Floodwood and Carleton, but was there turned southwestward because of the presence of the Superior lobe. The relations of this latest ice-movement from central Canada to the Glacial Lake Agassiz are such as to make necessary a radically different interpretation from that given by Upham in his monograph on Lake Agassiz.

Discussion

Mr. J. B. Tyrrell said: Mr. Leverett's paper can not but be of interest to every student of glacial geology in America, and especially to those who have been working in Canada, where the three great centers of ice-dispersion are located from which the ice traveled southward into the United States, for he has shown another point of connection between the Keewatin Glacier to the west and the Labradorean glacier to the east, through a large drainage channel from the former to the latter.

The presence of this drainage channel would appear to show clearly that the southern lobe of the Keewatin Glacier was of the same age as the Superior lobe of the Labradorean glacier, but I do not see why this should modify very materially the explanation of the formation of Lake Agassiz as given first by Mr. Warren Upham and afterwards somewhat modified by myself.[2]

It is quite probable that this lake had its beginning when the latest stage of the Keewatin Glacier began to retire northward, and it is possible that the water followed this glacier northward as far as the northern boundary of Minnesota, but it is also quite clear that as the Keewatin Glacier retired northward the Labradorean glacier advanced from the east into the basin of Lake Winnipeg, in many places as far as its western shore, though at this time it does not appear to have crossed the strip of land between Lakes Winnipeg and Manitoba, or to have reached the Manitoba escarpment to the west of the latter lake, but it terminated in a moraine which is now represented by islands in Lake Winnipeg and points on its western shore.

For greater definiteness this line of islands and stony points may be called "The Winnipeg moraine." This Winnipeg moraine was then the western or southwestern termination of the Labradorean glacier in its last advance into Manitoba. There is no question whatever about its existence and about the manner of its formation. The striæ of the Labradorean glacier are general on the rocks down the east shore of Lake Winnipeg, where they have been beautifully preserved by the overlying covering of lacustrine clays deposited on the floor of Lake Agassiz. In some few places the earlier striæ of the Keewatin Glacier have been preserved in depressions in the rock surface, which

[2] J. B. Tyrrell: The Genesis of Lake Agassiz. Journal of Geology, vol. 4, 1896, pp. 811-815.

are elsewhere completely covered by scorings made by the later Labradorean glacier. To the west of the Winnipeg moraine the striations on the rocks have been formed exclusively by the Keewatin Glacier from the north and northwest.

The lake itself, at all events for the greater portion of its existence, was bounded to the east by the front of the Labradorean glacier, and to the north by the front of the Keewatin Glacier.

The relationship of these two glaciers is beautifully shown by a section at the mouth of the Saskatchewan River, where 12 feet of stratified Lake Agassiz clays lie between the till of the Keewatin Glacier and that of the Labradorean glacier.

Lake Winnipeg is the diminished representative of Lake Agassiz, and even now it has but a precarious existence, for it is bounded to the north by a cliff of lacustrine clays. The outlet from the lake accidentally began where this clay was shallowest, near its northeastern extremity, and over a bottom of hard granitoid rocks, but if at some time the outlet should change to a position farther west, where the clays are thicker and the underlying rock is at a greater depth, the lake might very easily be more or less completely drained and we would have the Red River flowing down through the bottom of the basin that is now covered by the waters of Lake Winnipeg.

Mr. Warren Upham contributed the following remarks, which were presented to the Society at the meeting by Prof. Lawrence Martin: The conclusions of Mr. Leverett differ so much from my general view of the history of the glacial Lake Agassiz, presented in Monograph XXV of the U. S. Geological Survey, that I am moved to endeavor here to present friendly comments showing how I regard some of his views and arguments. He discriminates, as the abstract states, three sheets of the drift in northern Minnesota of different ages; but, instead, I consider them as practically contemporaneous in deposition, representing a tendency toward lobation where contiguous parts of the broad ice-sheet, confluent together, had respectively broad glacial currents from the northwest, north, and northeast, each of these somewhat lobate contemporaneous ice-fields bringing drift from the areas whence its currents came. Therefore the drift from the northwest is calcareous, while the drift from the north and northeast, the latter colored reddish by the red sandstone and shales of the Lake Superior basin, has little or no limestone. When the ice boundary was melted back at the end of the Glacial period, its marginal moraines, formed at any times of halt or readvance interrupting the general departure, were made up by whatever drift was in the adjoining past of the ice-sheet, so that our series of marginal moraines, in crossing Wisconsin, Minnesota, and the Dakotas, passes continuously across the several diverse drift sheets. Much of the glacial drift was borne along in the basal quarter or fifth part of the thickness of the ice-sheet, up to heights of 1,000 feet or more above the land surface, as shown by the esker of Bird's Hill, near Winnipeg, described in my Geological Society of America paper two years ago. Decaying granitic and other feldspathic rocks, deeply weathered before the Ice Age, yielded much drift and abundant boulders and smaller rock fragments, shaped by the glacial erosion and held in shape while frozen, forming a large proportion of the older drift and of the lower and most abundant englacial boulders, small fragments and fine drift, to be worn

off by the rasping ice. These fresher drift materials were carried forward in the ice-sheet to attain even higher levels than the older decayed drift. At the final melting such fresh drift on some areas was deposited as "a thin veneer," to use Mr. Leverett's words, upon the older general drift sheet and on its accumulations in the great marginal moraines, all these diverse types of the drift being laid down at the time of the melting away of the ice-sheet. The most remarkable contrast between Mr. Leverett's views and mine comes in his assertion that our grand moraines of northern Minnesota were amassed during a stage of glaciation wholly antedating the existence of Lake Agassiz, and that a relatively late ice accumulation and readvance spread over these abundant, steep, and high morainic hills without smoothing them down, depositing upon them a veneer of the latest fresh gray till. The late lobe of the ice-sheet stretched southward from the Red River valley to the vicinity of Des Moines, in central Iowa, and its departure was attended by the glacial Lake Agassiz, growing gradually north to the sites of Lake Winnipeg and the Saskatchewan River. Differing from Mr. Leverett, I feel sure that our massive Minnesota moraines were formed contemporaneously with the existence of the great glacial lake and with its gradual extension northward, and my opinion is that his veneering of fresh gray drift is merely the highest part of the englacial drift, massed on the moraines at practically the same time with their formation in the main part from lower and older englacial drift.

Mr. Leverett, in reply, said: The suggestion made by Mr. Tyrrell, that southwestward-bearing striæ in eastern Manitoba indicate that the latest ice-movement was from the northeast, is perhaps a correct one for that region. But in northern Minnesota the striæ with a southwestward bearing apparently pertain to the ice-movement that deposited the red drift. The ice which later came in from the northwest and deposited gray till over the red drift did not efface all the striæ of the earlier movement. This probably was due to the slight abrasive power of the clayey drift material which it carried.

GROOVED AND STRIATED CONTACT PLANE BETWEEN THE NEBRASKAN AND KANSAN DRIFTS

BY J. ERNEST CARMAN[3]

The paper describes the unique feature of a grooved and striated contact plane between the Nebraska (pre-Kansan) and Kansan drifts. Both sides of the contact plane are striated. Neither side is the mold of the other. The possible explanations are considered and the conclusion reached that glaciation produced the feature.

NEBRASKAN DRIFT OF THE LITTLE SIOUX VALLEY IN NORTHWEST IOWA

BY J. ERNEST CARMAN[4]

The paper traces a farther extension of the Nebraskan drift and compares the Nebraskan and Aftonian deposits of this region with those along the Missouri River.

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[3] Introduced by George F. Kay.
[4] Introduced by George F. Kay.

Mr. Frank Leverett called attention to the fact that in an unpublished paper read before this Society in December, 1904, he had described glaciated surfaces of the sort noted in Mr. Carman's paper, observed on the stones imbedded in the till of drumlins in the northern part of the southern peninsula of Michigan. These observations in the drumlins show that it is not necessary that the underlying drift should become cemented or indurated before such striæ are produced, and that the striation may go on in the course of deposition of a single drift sheet. In the locality discussed by Mr. Carman there should be conclusive proof outside of the glaciation of the till surface that the underlying till is markedly older than the overlying deposit.

ON THE PRE-GLACIAL MIAMI AND KENTUCKY RIVERS

BY N. M. FENNEMAN

(*Abstract*)

Two hypotheses are entertained concerning the regional preglacial drainage in southwestern Ohio and adjacent States: one, best stated by Prof. Joseph J. James, that this drainage was southwestward along the course of the present Ohio; the other, presented by Mr. Girard Fowke, that the Kentucky River flowed northeastward from its present mouth along the line of the Ohio and Miami rivers, reversed, to join a great west-flowing trunk stream which may be regarded as an extended preglacial Kanawha. The criteria for discrimination consist in (1) the depth of the rock surface along present and former stream courses; (2) local differences in the width of the Ohio Valley between bluffs, especially certain narrows near Cincinnati and one at Madison, Indiana; (3) the angles at which tributaries join the present master streams. From newer data on (1) it appears impossible that the drainage at the time referred to could have been northward from southwestern Ohio. There is no evidence of subsequent crustal warping. The rock surface declines at least 350 feet from west central Ohio to the mouth of Kentucky River, but is apparently decidedly higher below that point at Madison, Indiana. It is possible that local Pleistocene changes may have made a new valley there. Under (2) the chief point at issue is the narrows at Madison, which are not adequately accounted for by hardness of rocks, because there are other features of youthful drainage. This strengthens the supposition that the preglacial Ohio made a (not yet discovered) detour around Madison. The facts under (3), while not alone conclusive, favor southwestward drainage as at present (Fowke says the opposite). On the whole, the great point in favor of Fowke's theory is the narrows and elevation of the rock surface at Madison, but the slopes of the rock surface in western Ohio constitute an insuperable objection to this theory, except by assuming notable crustal movements of which there is no evidence.

RECENT STUDIES OF THE MORAINES OF ONTARIO AND WESTERN NEW YORK

BY FRANK B. TAYLOR

Discussion

Prof. H. L. Fairchild asked if the author had determined the direction of outflow of the waters drained away from the insular area or the tract of

exposed land surrounded by the ice-sheet. In an unpublished paper describing the glacial waters of the Mohawk and Black valleys it is shown that the high Adirondacks were at one time in the waning of the Labradorean ice-sheet exposed as bare highlands while surrounded by ice. The Hudson ice lobe and the Ontario lobe were yet united by a neck or strait of ice in the Mohawk Valley, and the drainage from the Adirondack area was southward across the strait of ice into the headwaters of the Susquehanna River.

CLOSING PHASE OF GLACIATION IN NEW YORK

BY H. L. FAIRCHILD

(*Abstract*)

As the Labradorean ice-sheet melted away from the north border of New York State, it allowed the water of the ice-bound Lake Iroquois to escape at Covey Hill Gulf and to pass around the northeast slope of the Adirondack highland. Being confined and directed by the ice-border, this stream-flow produced the extensive areas of bare rock in the towns of Mooers, Altona, and Beekmantown, formerly described by Woodworth.[5] The later stream-flow along the Altona rocks determined the level of a narrow lake lying northwestward, into which Lake Iroquois was lowered by the waning of the ice-front on Covey Hill, and for a time this lake succeeded Iroquois in the Ontario basin. It is proposed to call this water Lake Emmons (after Ebenezer Emmons, whose district in the first geologic survey of the State covered this area). The further weakening of the ice-border finally allowed Lake Vermont (named by Woodworth), which had previously been confined to the Champlain Valley, to succeed Lake Emmons, and in turn to occupy the Ontario basin. It is proposed to call this expanded water Lake Vermont-New York. These two water planes in the Ontario basin, inferior to Iroquois, are represented chiefly by delta sand plains on the larger streams. Eventually the waning of the ice east of the Champlain embayment allowed the glacial waters to become confluent with the sea, and the sealevel waters were thus established in both the Champlain and Ontario basins at the same time. The height of the marine beaches about Covey Hill is 525 feet, which definitely gives the amount of land uplift on the international boundary since the ocean transgressed that area. Maps exhibit the glacial drainage channels, the deltas, and the shorelines of the three water planes in the Champlain district and the four planes in the Ontario district.

Discussion

Dr. J. W. Spencer: The first survey of the Iroquois beach in northern New York was made by myself. The continuous shoreline could be traced to only a few miles east of Watertown, where I measured it 730 feet (subsequently by Fairchild at 733). Beyond, I found a series of magnificent deltas and sand plains. These were measured and regarded by me as the continuation of the Iroquois beach. Dr. Gilbert and I went over the field together. He regarded them as belonging to separate glacial lakes. Now Professor Fairchild extends my original surveys farther east, although shore features are

[5] New York State Museum bulletins, 83, 84.

here different from those south of Watertown. Regarding the marine beach of Gilbert Gulf, there are no marine shells, the calculated plain is too high for sealevel, and the distinct deposits of marine shells are not of identical epochs. Therefore there is no ground for the author's pronouncement of their marine origin.

East of Ogdensburg are beds of fine stratified clay with surface smoothed, polished, and striated. It is covered with sand. Lying on the clay are a very few small erratics, while no stones occur in the sand. This suggests that a glacial advance occurred after the clay beds had been deposited, but before the changed conditions arose which permitted the later accumulation of sand.

INTERMINGLING OF PLEISTOCENE FORMATIONS

BY B. SHIMEK

Published as pages 709-712 of this volume.

LOESS A LITHOLOGICAL TERM

BY B. SHIMEK

(*Abstract*)

The term "loess" has commonly been understood as implying a more or less distinct division of time. The facts are that there are several loesses deposited at different periods, and that loess does not designate a distinct period of time, but indicates rather a condition of deposition, as do such terms as "sandstone," "limestone," and "drift."

Discussion

Mr. F. V. Emerson: Loess is forming along the Missouri in central Missouri. During the dry, late summer frequent dust storms carry a yellow dust to the bluffs, where it gathers and is easily observed on exposed surfaces. This dust in all essentials resembles the material forming the thick loess beds.

Prof. G. Frederick Wright: In judging of the date of the various deposits of loess, it is important to keep in mind that throughout the entire period through which the ice was advancing there were each summer pouring forth from it powerful currents of silt-laden water, so that whenever there was recession of the ice-front, great or small, there might be an accumulation of loess which would be subsequently covered by the till of a later ice advance. It is well, therefore, to name such deposits after the various stages of advance of the ice.

But there was *par excellence* a period coinciding closely with the departure of the Iowa ice when silt-laden waters were so superabundant as to lead to the building up of the loess deposits along the Missouri and other rivers which have been especially under consideration. Here, as in China, there was a special period when the accumulation of loess exceeded its ablation. Both here and in China the erosive agents are now in the ascendant, so that

the loess is being transported to lower levels to be deposited along the flood-plains of the present streams and largely into the ocean itself. Whatever agency the wind may have had in distributing the loess, it was, in America, glacial-laden streams which brought the material into the vicinity of the present large deposits.

Mr. Frank Leverett: Professor Shimek's suggestion that the name Sangamon should be extended to the loess deposit that overlies the Sangamon soil does not seem to me a step in the right direction. The Sangamon soil appears to have been developed under cool, and possibly humid, conditions which followed somewhat closely the Illinoian stage of glaciation, and in which decay of organic matter in the soil did not keep pace with plant growth. At that time there seems to have been relatively little dust in the air, or a condition unfavorable for loess deposition. This in time gave place to a warmer and probably less humid condition under which dust-laden winds transported and deposited the loess. The earlier phase in which humus accumulates dominated should be distinguished by a separate name from the later phase in which loess deposition dominated. Certain Russian geologists have made a clear separation of this sort and have named the earlier humus-forming phase the forest phase, and the later loess-depositing phase the steppe phase of the interglacial stages.

GROS VENTRE SLIDE

BY ELIOT BLACKWELDER

(*Abstract*)

In the Gros Ventre Valley of western Wyoming a part of the slope has been quietly moving down toward the river for several years. In many respects the operation is suggestive of glaciers. The slide was described, its history summarized, and the geological conditions responsible for it were pointed out.

CENOZOIC HISTORY OF THE WIND RIVER MOUNTAINS, WYOMING

BY L. G. WESTGATE AND E. B. BRANSON

(*Abstract*)

A preliminary account of the successive peneplains, partial peneplains, and terraces of the southern part of the Wind River Mountains, the preglacial gravels capping some of the terraces, and the relation of the terraces to deposits of an earlier and a later glaciation.

STABILITY OF THE ATLANTIC COAST

BY DOUGLAS WILSON JOHNSON

(*Abstract*)

The results of the Shaler Memorial Investigation of shoreline changes along the Atlantic coast indicate that there has been no appreciable subsidence of

this coast within the last few thousand years. The phenomena which seem to indicate recent subsidence appear to fall into three groups: (1) Fictitious appearances of subsidence which are produced by wave action on a retrograding shoreline without any change in the level of land or sea; to this group belong many instances of submerged stumps, peat exposed at low water on the seaward side of barrier beaches, erect trees recently killed by the invasion of salt water, etc. (2) Phenomena produced by a local rise in the high tide surface, due to a local change in the form of the shoreline, unaccompanied by any general change in the relative level of land and sea; in this group may be found examples of practically all phenomena ordinarily attributed to a recent subsidence of the land. (3) Phenomena produced by an actual subsidence of the land or rise of the sealevel which occurred some thousands of years ago; in this group belong many of the deeply buried peat deposits and submerged stumps. The evidence of coastal stability consists of (1) the form and position of successive beach ridges, the oldest of which were built by the waves thousands of years ago, yet later than the deeply buried peat deposits; (2) the position of abandoned marine cliffs on which the waves can not have worked in recent time, and (3) the absence of a fringe of dead trees on those portions of the coast which are exposed neither to direct wave attack nor to local fluctuations of the high tide surface. It is concluded, with reference to the Atlantic coast, that the land can not have subsided as much as a foot within the last century; that there can have been no long continued progressive subsidence at so high a rate as one foot per century, within the last few thousand years, and that no evidence thus far available can be regarded as satisfactory proof of any degree of recent subsidence, either spasmodic or progressive.

Discussion

Dr. C. A. Davis: The physiographic evidence to be gathered on the exposed shores is not such as to show slight changes of level as the range of the tides is so great; hence recent subsidence can neither be proved nor disproved by it. While we have the possibility of a general elevation of the tidal surface because of changes in the shores of the Atlantic, there is no evidence that this has occurred or that such elevation is going on either in tidal records or elsewhere. The evidence of the salt marshes that subsidence is going on, since it is to be presented in a paper to be read at this meeting, will not be mentioned now, but it may be said that at Nantasket Beach there is a small area of salt marsh which shows recent change of level, in that if there had been stability for as much as 1,000 years it could not exist as a salt marsh, because the plant remains would have built up above the reach of the tides. Four or five miles southwest of Nantasket is an area of salt marsh with stumps of trees in place more than 2 feet below the level of ordinary high tides, and partly buried in salt marsh peat, which must have been formed by the gradual change of the relation of the high tide to the bottom. No sudden change in the relation would account for this accumulation, and the change has not yet ceased. The tidal waters find their way to this area by tortuous channels, and any change of tidal level on the marsh must have been accompanied by greater ones at the beach, as the tidal wave has more direct access to it.

Dr. J. W. Spencer: In support of the present stability of the land and sea, I have found from analysis of the daily fluctuation of the Great Lakes that there has been no change of even a tenth of an inch since 1850-1855. (See chapter xxxi and appendix, "The Falls of Niagara," Geological Survey of Canada, 1907.)

Prof. A. C. Lane referred to the work of J. R. Freeman for the Charles River Commission and since, and said that his observation of the Nantasket region referred to led him to believe a subsidence of 5 feet between the formation of the first connecting beach and the present might be allowed.

Dr. H. B. Kümmel: Since the results of Professor Johnson's observations have come to my attention I have been very much interested in determining the origin of the unqualified assertion so frequently seen in text-books, that the coast of New Jersey is subsiding at the rate of 2 feet per century. I found that in 1857 Prof. George H. Cook, then professor of geology at Rutgers College, New Brunswick, New Jersey, read a paper before the American Association for the Advancement of Science, in which he set forth the various facts which led him to conclude that the coast of New Jersey had suffered a long-continued and slow subsidence, and that this downward movement was still in progress. At the close of his paper he cited a number of facts bearing on the rate of subsidence, and he concluded that "we may, with some degree of probability, state the average subsidence in the district where the observations were made as two feet in a century." Referring to facts in relation to the rate of subsidence, his final statement was, "It is not unlikely that other and more numerous observations may give a different result."

On the basis of this paper, published in the American Journal of Science in November, 1857, the present subsidence of the New Jersey coast at the rate of 2 feet per century was apparently accepted as demonstrated, and statements to that effect were published thereafter in Dana's Manual of Geology, at first on the authority of Professor Cook, and later without authority, as a well known and established fact.

In 1885, in the report of the State Geologist of New Jersey for that year, Professor Cook reviewed all the data in his possession bearing on changes along the New Jersey coast, and while he still held the opinion that the coast was sinking, he stated that it was "at a rate which is not yet quite definitely established."

Two or three years later, after the topographical survey of the State was completed, certain facts in regard to the relative level of high tide in the ocean and in the lagoons behind the barrier beaches were brought to Professor Cook's attention, and he then realized that some of the facts upon which he had very strongly relied as proving present subsidence were probably to be differently interpreted; so that I think I am safe in saying that at the time of his death, in 1889, he was not nearly so strongly convinced that the coast of New Jersey is sinking at the present time as he was thirty years earlier.

Professor Johnson replied as follows: Referring to Mr. Spencer's comments, I might say that it was the intention of Mr. J. B. Tyrrell, had he not been compelled to leave early, to present certain evidence recently acquired

by him tending to show that there had not been any marked change in the relative level of land and sea along the southwest coast of Hudson's Bay within the last two or three hundred years; certainly nothing like 5 feet in that length of time. His evidence is based on a comparison of carefully made maps. If his interpretation is correct, it is an interesting example of coastal stability farther north than our observations have extended.

Replying to Dr. Davis, it is true that the physiographic evidence of coastal stability is not as sensitive as one could wish. All physiographers will recognize the difficulty of proving absolute stability by beach ridges which may vary in height several feet. On the other hand, the physiographic evidence is very reliable and seems to prove conclusively that there can have been no marked subsidence of the coast for several thousand years; certainly the deeply buried peat can not possibly be explained on the theory of recent subsidence, for the beach ridges prove that the coast can not have subsided more than a very few feet at most, whereas the peat descends to much greater depths.

I believe I have never held that there can have been no subsidence whatever in recent times. I have always held that the physiographic evidence did not preclude the possibility of a slight subsidence in the last few thousand years. On the other hand, I have held, and still believe, that there is no reliable evidence that even a slight subsidence has occurred in recent times. Tidal fluctuations and other shore changes will account for the apparent evidences of subsidence.

Dr. Davis seems to believe that only gradual changes in the relative levels of land and sea could account for the dead stumps he has described, and that therefore the theory of tidal fluctuations will not account for them. I should have said that inasmuch as changes in the form of the shore often take place gradually, the local rises of the high tide surface which produce apparent subsidence also take place gradually. Only in exceptional cases is the rise so sudden as in the Scituate case which I described.

SOME COASTAL MARSHES SOUTH OF CAPE COD

BY CHARLES A. DAVIS

(*Abstract*)

A report on a continuation of the work on salt marshes in the vicinity of Boston, the results of which were reported at the Boston meeting in 1909. The structure of salt and brackish marshes on the south side of Cape Cod and on Long Island is described, and the evidence this bears in favor of recent coastal subsidence is discussed.

Discussion

Prof. J. B. Woodworth remarked on the apparent validity of the argument for subsidence based upon the structure of *Spartina patens* marshes and the contradictory evidence as to a very recent subsidence of the coast pointed out by Prof. D. W. Johnson from his finding successive beach crests of ancient

and modern date at the same level. He inquired what Dr. Davis would offer as an explanation of the failure of the older beaches to show subsidence.

Prof. A. W. Grabau asked for a statement as to the depth of the peat deposits in the Long Island region and the rate of growth of the salt peat.

Dr. Davis replied: Two hypotheses may account for the lack of apparent accord in the physiographic evidence of the beach and other phenomena cited with the botanic evidence of subsidence: (1) The beach phenomena may not be so old as supposed. (2) They may have been formed by high storm tides long ago to a level which has been brought down to the present one by subsidence, as trees are apparently brought down within reach of tidal waters in the 200 to 500 years of their lives. The greatest subsidence found in the brief studies in Long Island was about 10 feet. The only records showing rate of subsidence found were in the vicinity of Boston at the end of the field season. In two localities the turf of salt marshes along long-established railways was found to contain coal cinders from locomotives in the upper 3 or 4 inches. One of the lines had introduced the use of coal in its locomotives in 1861, and by 1865 had equipped all of its locomotives for burning coal.

CRITERIA FOR THE RECOGNITION OF ANCIENT DELTA DEPOSITS

BY JOSEPH BARRELL

Published as pages 377-446 of this volume.

ANCIENT DELTA DEPOSITS

BY A. W. GRABAU

(*Abstract*)

After a brief reference to the pre-Cambric or early Cambric delta fan of the Pacific province and the Torridon of Scotland, the following were discussed with especial reference to their stratigraphic and paleontologic characters and their bearing on paleogeography:

The late Ordovicic and early Siluric fans of the Appalachian region.
The Shawangunk dry delta fan and its relationship to the Salina desert.
The Esopus delta and its relation to the Oriskany deposits.
The early Devonic talus breccia of Michigan and western Ontario.
The Old Red of Scotland and the Catskill group.
The Pocono, Mauch Chunk, and Pottsville.
The Triassic fans of America and western Europe.

MISSISSIPPIAN DELTA IN THE NORTHERN NEW RIVER DISTRICT OF VIRGINIA

BY E. B. BRANSON

Published, under the title "A Mississippian delta," as pages 447-456 of this volume.

Discussion of the Preceding Three Papers

Dr. J. M. Clarke referred to the continuous presence of Devono-Carboniferous continental deposits on all the eastern frontage of the Appalachians, especially to the delta work presumably of the Saint Lawrence River, represented by the Bonaventure formations of the Gulf of Saint Lawrence.

Dr. David White: The Pocono formation is essentially a unit, though erosionally disconnected in its extension from southwest Virginia to the Mauch Chunk region of Pennsylvania. Along its easternmost belt it consists of well washed and comparatively regular gray grits and sandstones, with interbedded shales and coals. The character and extent of the sandstones suggest coastwise distribution and differentiation of the material. The presence of coals, which throughout the greater part of the eastern border of the existing Pocono zone are nearly if not quite of workable thickness, and the occurrence, at many points at least, of roots in their place of growth in the underclays, demonstrate extreme shallowness of water cover at the time of deposition of the coals. The relative narrowness of the longitudinal zone of typical Pocono sandstones and coals points either to the existence of an estuary extending from the Tennessee region northward along the Appalachian trough at this stage of the earliest Mississippian or to the presence of barriers separating and essentially isolating narrow and shallow eastern basins from the broader marine expansion on the west. In the former case the narrow estuary, which seems more probable, was the starting point for an extensive northwestward transgression, with the early development of marine conditions. The rapid thickening of the beds toward the east (shoreward) and the increase of coarse detrital matter in the same direction harmonize with the recognized existence of drainage from the eastern land out into the basin. The latter, as shown by the coal deposition, included a broad filled zone standing at times at or above sealevel. It is probable, however, that the areas of actual Pocono "delta" are now obliterated by erosion.

Throughout most of the region or zone of typical Pocono sedimentation marine fossils have not been found. An exception is the Broad Top field, where brachiopods and other marine mollusks occur in the lower part of the formation, which there maintains a thickness of over 1,000 feet, though the formation is very much reduced at the Allegheny front.

There is no evidence that the Mississippian sea was at any time deep in the Appalachian trough, a feature already pointed out by Ulrich. The presence of conglomerates, of old soils, breccias, and land plant remains at various horizons in different areas of the post-Pocono Mississippian, indicates a number of intervals and regions of exposure of portions, at least, of the trough. These episodes will no doubt eventually be fitted into a somewhat complicated, though very interesting, history of the Appalachian trough during Mississippian time.

Dr. G. W. Stose: In discussing Mr. Branson's paper, I wish to refer to the occurrence of the Price sandstone in the Abingdon quadrangle, Virginia, some 30 miles to the southwest. There the Price has a rather uniform thickness of about 600 feet for 50 miles along the strike, showing no thickening due to deltas. There is a marine Mississippian fauna in the upper half of the for-

mation and thin coals only at the very top. It is concluded that these sands were derived from deltas, such as the one described by Mr. Branson, of streams heading in the older rocks to the east and flowing across a coastal plain to the inland sea, and there distributed along the shore by shore currents.

Mr. Arthur Keith called attention to a statement by Professor Grabau that a certain type of cross-bedding characterized continental deposits, cited the common occurrence of cross-bedding in marine and continental beds, and requested Professor Grabau to inform the Society as to the difference seen between marine and continental cross-bedding. Such distinctions would be very useful as criteria on account of the easy recognition of cross-bedding.

Prof. E. T. Wherry: At the northern edge of the Triassic in eastern Pennsylvania conglomerates occur which, judging from their character and distribution, are to be regarded as delta deposits.

Dr. H. B. Kümmel raised the question whether a distinction was not to be made between ancient alluvial fans wholly subaerial in origin and formed wholly independent of bodies of standing water and true deltas. Some of the instances of deltas cited in the discussion seem rather to be alluvial fans similar to those now being formed in the west at the foot of high mountains.

The authors made the following replies:

Professor Barrell: A study of criteria to separate the submarine and subaerial deposits of deltas brings out clearly the need of more refined comparative studies of modern sedimentation under a variety of conditions. It is evident, however, that certain criteria are not to be used according to their mere presence or absence, but rather according to their specific characters and dominance. Cross-bedding may be cited as an example, present in marine, fluviatile, and eolian sands, but presumably showing distinctive characters in each case.

In reply to the comment of Dr. G. I. Adams as to the apparent confusion which is being introduced of marine formations with delta deposits, it may be said that by definition deltas involve both subaerial and subaqueous phases, since they are built against permanent bodies of water. On the other hand, marine beds of mud or sand should not be regarded as belonging to deltas unless there is evidence that they passed on the landward side into synchronous fluviatile deposits. There is no inherent distinction between the bottomset beds of a delta and the offshore bottom deposits opposite a river mouth, where deltas have been unable to form. Delta conditions involve the conception of certain *relations* between contemporaneous fluviatile and offshore deposits, not the *nature* of the beds themselves, for these are merely fluviatile and marine.

Professor Grabau: The two types of delta—sea-shore and subaerial fan—are probably to be recognized in the older deposits. Of the sea-shore deltas, in part subaerial, the Bald Eagle, Juniata, Tuscarora, and perhaps Shawangunk and Pottsville. The Longwood is most probably a subaerial fan, as there are no known marine parts of this deposit. The same is true of the

Triassic deposits of eastern and western North America, though those of western Europe may perhaps come in part under the first group.

The distinction between marine and continental types of cross-bedding is not easy, chiefly because our observations are too limited. We have, however, the following: Hobbs has shown that cross-bedding of a torrential deposit, such as the Guadix and related formations of comparatively recent origin, consists of a series of diagonal and horizontal beds many times repeated, and the diagonal beds all dipping in some one direction, while the successive horizontal and diagonal series are of moderate thickness, perhaps not over 6 or 8 feet, and not much less. Such cross-bedding has not yet been described from undoubted marine strata, nor is it conceivable how it can be formed under the sea. Walter Huntington and others have shown that the cross-bedding, with the successive series dipping in all directions and separated by erosion planes, is characteristic of eolian deposits due to migrating ripple-marks, and can produce this structure on a large scale under the sea, except in sand-bars, when it would have only a linear extent. So far, then, as we now know, cross-bedding on a large scale, except when of only lineal or limited extent, is characteristic of continental deposits. Fossiliferous eolian deposits are illustrated by the Lunegarth limestone.

STRUCTURE OF ESKER FANS EXPERIMENTALLY STUDIED

BY T. A. JAGGAR, JR.

(*Abstract*)

Deltas formed by miniature cavern torrents were shown and cross-sections made by slicing them. The conclusions arrived at concern the effects of sheet-floods, of a raised or lowered lagoon level, of variation in load of detritus and variations in velocity and volume of current. These effects appear in the symmetry and asymmetry of ground plan of deltas and in the relations of topset and foreset beds.

EFFECT OF RAPID OFFSHORE DEEPENING ON LAKE-SHORE DEPOSITS

BY RUFUS MATHER BAGG, JR.

(*Abstract*)

Local beach pebble deposits on the shore of Little Sister Bay, near Ephraim, Wisconsin, on the east side of Green Bay, consist of Silurian (Niagara) limestone pebbles beautifully rounded by wave action in a protected cove, where the water grows deep very rapidly offshore. No similar occurrence is to be found anywhere in the immediate neighborhood along this shore where similar conditions prevail. In all other sections the flat limestone fragments remain in more or less of their original condition or but slightly water-worn.

STRUCTURE OF THE HELDERBERG FRONT

BY A. W. GRABAU

(*Abstract*)

The Helderberg front is the northern extension of the westernmost belt of the Appalachian folded area, left after extensive erosion. The former extent

east of the Hudson is partly indicated by Becraft Mountain and Mount Ida. The basal part is of folded Hudson strata unconformably succeeded by late Siluric, showing various phases of overlap. The Appalachian folds are of the usual asymmetric type, while the range from near Rosendale to Catskill and beyond is complicated by one or more pronounced overthrusts. The first of these was described by the author from Kingston, and subsequently more fully discussed by Van Ingen and Clark. Chadwick has described a part of the thrust at Saugerties and the author has determined its character near Catskill. Several new sections from this last region were presented.

Discussion

Prof. J. B. Woodworth called attention to the fact that in southeastern New England the carboniferous areas show overthrusts to the southeastward and not to the westward. It should not, therefore, be assumed, as has been done, that there has been everywhere in the Appalachian geological province an overthrust as from the Atlantic basin.

SUCCESSION IN AGE OF THE VOLCANOES OF HAWAII

BY T. A. JAGGAR, JR.

(*Abstract*)

The plan of the Island Hawaii shows a symmetry in accordance with the structure of the several volcanoes, and the activity of two of them, which leads to the conclusion that there is a record of succession shown. This is at variance with Dutton's conclusion that no age of beginning of activity for a given vent can be assigned. The writer not only postulates a succession in age of beginning and closing activity in the older vents, but he argues that Kilauea is not the youngest vent. The argument presented suggests a permanent lava column continuously rising.

BIBLIOGRAPHY OF THE MAMMOTH CAVE

BY HORACE C. HOVEY

(*Abstract*)

This catalogue contains the titles (with brief descriptive notes) of all known publications concerning Mammoth Cave and its contents, comprising descriptions of its antiquities, scenic features, geology, environment, cavern fauna, and flora.

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